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WEST COAST PICKET FENCE FEASIBILITY STUDY
DURING STORM-FEST I. FIELD PROGRAM SUMMARY

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The West Coast Picket Fence was a series of seven special rawinsonde sites interspersed among the seven regular rawinsonde sites along the west coast. In addition to the improved spatial resolution, rawinsondes were launched every 3 h at all 14 sites to improve time resolution during four Intensive Observing Periods. The objective was to demonstrate the feasibility of the Picket Fence observations by providing improved upstream boundary conditions for the forecasts of mesoscale weather events in the Midwest during the STORM-Front Experiment Systems Test in February and March 1992. The Picket Fence field experiment observations at each station are summarized during the four Intensive Observing Periods, which included a variety of meteorological systems passing the west coast.

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1. OVERVIEW OF WEST COAST PICKET FENCE

a. STORM-FEST

The goal of the STORM-Fronts Experiment Systems Test (STORM-FEST) was to provide research background and operational experience for the STORM I Field Experiment planned for 1994 in the central United States. Specifically, there were three main objectives of STORM-FEST: (*i*) to investigate the mesoscale structure of fronts and other mesoscale phenomena associated with winter storms that occur in the central United States; (*ii*) to test and evaluate the utility of the various observing systems, observing networks and information systems that will be deployed for STORM-FEST and STORM I; and (*iii*) to investigate mesoscale weather prediction capabilities and limitations in active frontal regions with the goal of improving forecast performance.

To accomplish the objectives of STORM-FEST, an array of operational and research observational instrumentation was deployed in a limited region within the central U.S. (see STORM-FEST Operations Plan, 1992). The primary upper-air data set obtained from the experiment was from the three to six hourly sounding data provided by the approximately 20 National Weather Service (NWS) sites within the STORM-FEST region and from the Wind Profiler Demonstration Network (Fig. 1). These soundings were supplemented by Cross-chain LORAN Atmospheric Sounding Systems (CLASS) and CLASS-type sounders. The CLASS units were positioned within the STORM-FEST domain to fill in the gaps in the coverage of the operational sounding network and array of profilers. The STORM-FEST observational systems provided upper air observations with an average horizontal spatial resolution of 150 to 200 km. Higher horizontal and vertical resolution was achieved in localized regions from conventional and Doppler radars and through the deployment of research aircraft. Additionally, new objective analysis and four-dimensional data assimilation (4DDA) techniques for the mesoscale provided dynamically consistent gridded data sets from which a documentation of the three-dimensional structures and the evolution of frontal zones will be made.

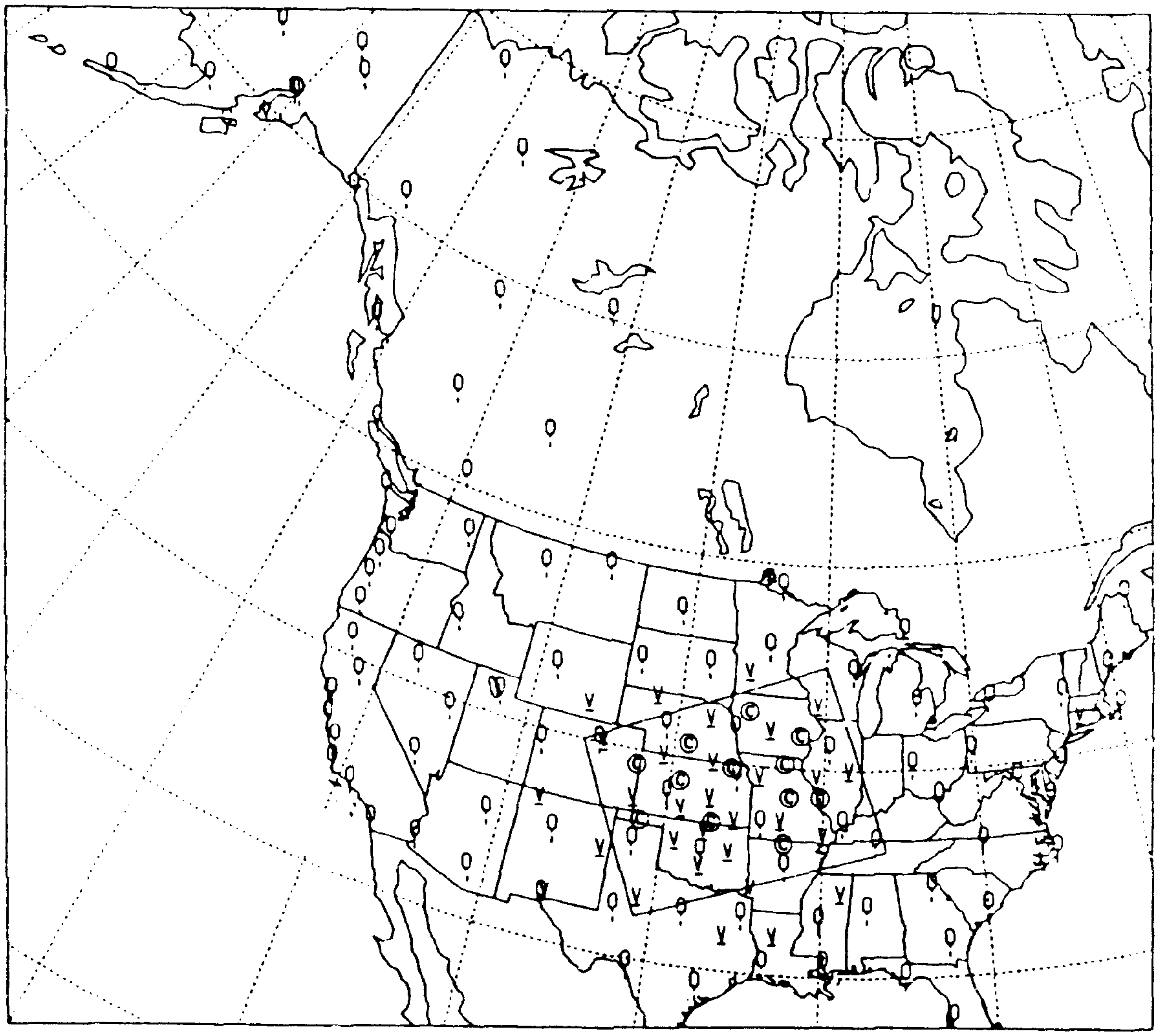

Fig. 1 Upper air station (balloon symbol for rawinsondes; C for CLASS sites; and V for radar wind profilers) within the STORM-FEST domain (bo.. over Midwest), and in the West Coast Picket Fence from Pt. Hardy, British Columbia on the north to San Diego, CA on the south. The NWS Western Region stations between the STORM-FEST domain and the west coast and selected Canadian sites also participated (STORM-FEST Operations Plan 1992).

b. **Scientific basis for Picket Fence**

The scientific basis for the West Coast Picket Fence is that a certain class of forced mesoscale phenomena is triggered by the interaction of the environmental flow with mesoscale circulations associated with topography, diurnal heating patterns, etc. Given accurate representations of the forcing mechanisms and the environmental flow, the timing and location of the outbreak of these mesoscale phenomena may be predicted more accurately. Even though massive vertical redistribution of energy and momentum may occur when the mesoscale circulation is triggered, prediction of the downstream advection and perhaps propagation (relative to the "steering flow") of the mesoscale system will ultimately be limited by the accuracy of the environmental flow specification. Consequently, this class of forced mesoscale phenomena will require an improved understanding of the forcing mechanisms and observations of the environmental flow in the domain plus the upstream systems that will enter the domain during the lifetime of the mesoscale phenomena.

In many cases, the environmental flow features (e.g., jet streaks, short waves, or more generally, potential vorticity anomalies) that trigger the mesoscale development have smaller space and time scales than can be resolved effectively by the present rawinsonde network upstream of the mesoscale target area. The only solution thus far has been to increase the frequency of the rawinsonde releases in the upstream operational network to improve the effective spatial resolution of those phenomena that pass that station. However, many aspects of the smaller scale features such as a jet streak may be poorly depicted by the coarse temporal and spatial resolution of the operational rawinsonde network.

The mesoscale prediction problem is greatly increased when the upstream environmental features originate over, or propagate from, the Pacific Ocean during the period of interest. Present satellite-based remote sensors do not have the vertical and horizontal resolution to accurately specify the environmental conditions associated with jet

streaks, short waves, etc. Even if improved surface specifications of pressure, temperature and humidity were available from a network of drifting buoys to "anchor" the satellite profiling techniques, the energetic and rapidly moving jet streaks and short waves would be unlikely to be resolved accurately by present satellites. Although wind reports from commercial aircraft do provide observations at about 10-12 km elevation in jet streaks, the coverage over the Pacific is confined to the great circle flight tracks between the U. S. and Asia, which leaves large data gaps. Another proposed solution for the Pacific Ocean data gap during STORM I has been to have special aircraft reconnaissance. One advantage of such aircraft is the flexibility to direct them to target areas within their operating range. However, a limited ability exists to predict that far upstream (over a data-sparse area) where and when the relevant environmental forcing features will be approaching the west coast of the U. S. In addition to having limited elevation capability (turboprop aircraft only operate up to about 300 mb) and time resolution (due to aircrew rest periods), this is an expensive solution because of operating and basing costs and the cost of the expendables. Thus, it was desirable to explore other options for providing upstream boundary conditions during STORM I, and to demonstrate their feasibility during STORM-FEST.

The Naval Postgraduate School was funded during STORM-FEST to demonstrate the feasibility of improving the accuracy of the upstream boundary conditions via a "West Coast Picket Fence" of observing sites along the west coast of the U.S. (Fig. 1). Seven new observing sites were established between the five operational National Weather Service (NWS) rawindsonde stations (Table 1) and both the special and operational sites sampled every 3 h rather than the regular 12 h interval. The U. S. Air Force site at Vandenberg AFB, California and the Canadian Atmospheric Environmental Service site at Pt. Hardy also participated. Rather than attempt to resolve the conditions over the Pacific, the goal was to intercept and accurately observe the jet streaks and short waves as they crossed the coast and approached the mesoscale target area. Given that the additional sites effectively

Table 1 West Coast Picket Fence locations that included National Weather Service (NWS), Canadian, U. S. Air Force and special sites.

Location		Elevation (m)	Latitude/ Longitude	Call sign
1. Port Hardy	Canadian	17	50 43' 127 29'	YZT
2. Quillayute WA	NWS (contract)	56	47 57' 124 33'	UIL
3. Olympia WA	Special (Note 1)	59	47 02' 122 52'	OLM
4. Salem OR	NWS	61	44 55' 123 03'	SLE
5. Cottage Grove, OR	Special (Note 2)	195	43 48' 123 04'	CGO
6. Medford OR	NWS	397	42 19' 122 52'	MFR
7. Redding CA	Special (Note 3)	177	40 36' 122 25'	RDD
8. Williams CA	Special (Note 4)	25	39 09' 122 05'	ILA
9. Oakland CA	NWS (contract)	6	37 48' 122 16'	OAK

Table 1 Continued.

Location		Elevation (m)	Latitude/ Longitude	Call sign
10. Monterey CA	Special (Note 3)	30	36 36' 121 53'	NPS
11. Paso Robles CA	Special (Note 3)	249	35 38' 120 44'	PRB
12.Vandenberg CA	U.S. Air Force	100	34 33' 120 37'	VBG
13. Point Mugu CA	Special (Note 5)	2	34 07' 119 07'	NTD
14. San Diego CA	NWS (contract)	134	32 34' 117 10'	NKX

Notes: (see also the Acknowledgments)

1. Launches by University of Washington and Submarine Group 9
2. Launches by Oregon State University
3. Launches by Naval Postgraduate School and Mobile Environmental Team personnel
4. Launches by Naval Postgraduate Schooi and University of California at Davis
5. Launches by Pacific Missile Test Center

doubled the spatial resolution along the west coast, the sites were dubbed as a "picket fence" through which any approaching feature would be detected.

A scientific justification for the picket-fence approach is provided by the experience with nested grid models of atmospheric phenomena. In the nested grid technique, the boundary conditions for the high resolution inner grid are provided by the time tendencies predicted on a coarser resolution grid that surrounds the inner domain. Many studies (see references in Anthes 1983; Ross 1986) have shown that one of the primary limitations to the accuracy of the solutions on the inner grid is the accuracy of the boundary conditions provided on the edge of that grid. After the time it takes for the coarse grid information provided at the upstream boundary to fill the inner domain, the solution tends to be no more accurate than if the nested grid had not been used. That is, a fundamental limitation to the predictability of the inner domain solution will be the accuracy of the upstream boundary conditions (Anthes 1986).

The ultimate application of the picket-fence idea would be to have a ground-based set of profiling instruments upstream (to the north and south as well as to the west as in this test) of the prediction domain that would observe the winds, temperatures, humidities, etc., continuously. Given an adequate horizontal spacing between such sites, a picket fence system would continually monitor the boundary fluxes of energy, mass, momentum, humidity, etc. In principle, such a boundary condition specification to the west, north and south could reduce the need for spending vast amounts of money to improve the observational capability over the Pacific Ocean and over the data-sparse Canadian and Mexican regions.

In the application to STORM I, the accuracy of the environmental conditions specified upstream will ultimately limit the predictions on the STORM I domain. The hypothesis being tested in STORM-FEST is that a west coast picket-fence approach to specifying these upstream condition will be a more accurate and cost-effective approach than the aircraft reconnaissance approach. In addition to improving the success of

STORM I, such a demonstration would have long-range implications for establishing a dense set of ground-based remote sensors along the west coast and along the northern and southern borders to improve mesoscale weather prediction over the U.S. in the future.

c. Operations strategy

The principle behind the picket fence feasibility test was that the combination of special and regular rawinsonde sites along the west coast would provide accurate boundary forcings of the meso-α forecast model. The picket fence approach would provide higher horizontal and temporal resolution of the meso-α forcing along the west coast, which was expected to be a maximum during periods when jet streaks or strong short waves crossed the picket fence. Thus, the primary forecast decision was to predict the time at which the leading edge of the jet streak or short wave would reach the coast. However, an additional requirement was that this feature would subsequently trigger some mesoscale weather event within the STORM-FEST domain over the central U.S. (Fig. 1). In split-flow weather regimes, a short wave may cross the coast and then move along northern or southern paths that do not affect the STORM-FEST region.

Another consideration was that the Picket Fence operations should be coordinated with the Air Force Reserve WC-130 aircraft reconnaissance program in the eastern Pacific organized by Dr. M. Shapiro of the NOAA Wave Propagation Laboratory. These aircraft missions were to be centered on the 00 UTC synoptic time so that the dropwindsondes could be entered into the National Meteorological Center (NMC) data analysis system. Unfortunately, the WC-130 aircraft was only available after 1 March, and only was a consideration during the last Picket Fence Intensive Observation Period (IOP).

These considerations led to a "most desired" timeline for the Picket Fence Intensive Observing Period (IOP) that would begin at 00 UTC (16 local) as in Fig. 2. In the ideal scenario, the Picket Fence IOP would start as the short wave or jet streak crossed the coast and would end 48 h later (Fig. 2). The STORM-FEST domain IOP would start 36 h after the Picket Fence IOP in order to sample a frontal passage at (say) Kansas City about 60 h

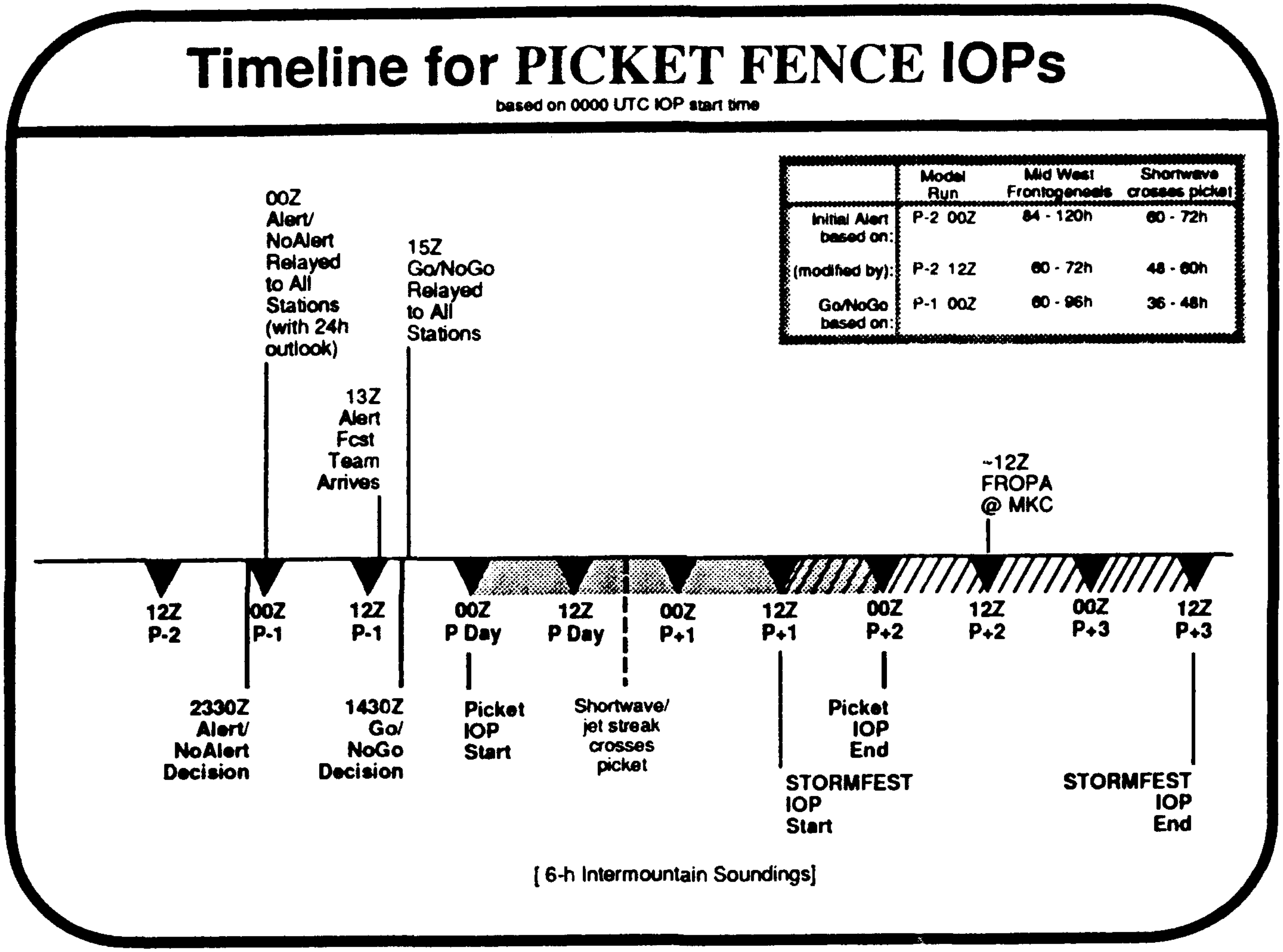

Fig. 2 Timeline for a Picket Fence Intensive Observing Period (IOP) beginning at 00 UTC (00Z) on P Day in relation to timing of STORM-FEST IOP and when various alerts, briefings, GO/NO GO decisions had to be made. The insert describes the time of the forecast fields necessary for predicting the Midwest and Picket Fence events.

after the beginning of the Picket Fence IOP. In a fully coordinated experiment, the National Weather Service (NWS) Western Region rawinsonde sites between the west coast and the STORM-FEST domain (Fig. 1) would be activated for 6-h soundings to provide improved temporal resolution of the short wave or jet streak in that region.

Another important factor in the scenario in Fig. 2 is that the NWS sites in the Picket Fence had to be alerted 24 h in advance of the Picket Fence IOP in order to plan for the 3-h launch schedule. In practice, a similar alert time was required at the special sites since the personnel, who were generally off-site, had to proceed to the site in time to make the 00 UTC observation. The alert could be cancelled (a No Go decision) by 15 UTC if the latest (12 UTC) analyses/forecasts or satellite imagery indicated the expected conditions would not materialize. In order to provide the 24-h alert, the Picket Fence forecast team (D. Titley, P. Hirschberg, G. Dunnavan and M. Jordan) used analyses and forecasts at 12 UTC, which is 48 h prior to the anticipated Picket IOP beginning. More importantly, this time is 96 h prior to when the mesoscale weather event was expected to be existing over the central U.S. Even longer (120 h to 168 h) forecast fields were regularly used to provide an outlook for future Picket Fence operations. It is emphasized that the features being forecast were originating or tracking across the data-sparse Pacific Ocean during these long intervals. These forecast requirements were thus at the margin of present capability for medium-range weather forecasting. Thus, the general strategy was to detect potential short waves at 500 mb at the longest forecast intervals and then follow the evolution in the shorter term forecasts originating each 12 or 24 h. If this sequence of forecasts provided a consistent representation of these short-wave evolution/translation, more confidence was gained in the likely occurrence of the short wave.

As the candidate short wave approached the west coast, regular communication with the STORM-FEST forecasters was maintained to establish a consensus scenario. In addition, discussions with the STORM-FEST management team were initiated to determine if a STORM-FEST IOP was likely to be called in association with the potential

Picket Fence IOP. Responsibility for alerting the NWS sites within the Picket Fence and within the Western Region resided with the STORM-FEST management team. In some cases, the Picket Fence was initiated but the Western Region stations could not be used due to limited resources. Unfortunately, agreement could not always be reached with the STORM-FEST management team on a coordinated IOP throughout the system. A description of which observing systems were activated during each Picket Fence IOP is given below in Section 3.

d. **Planned research strategy**

Some preliminary plans for research with the Picket Fence observations are given here to illustrate the data requirements to be met. The first step will be to document the additional fluxes of mass, heat, momentum, moisture and energy resolved with various combinations using the 12-h NWS-only rawinsondes as a standard. The observations at the NWS (here NWS will be taken to include the Vandenberg and Pt. Hardy sites as well) and at special sites will be mapped to a vertical cross-section along the west coast and converted to normal wind components relative to the cross-section. Fluxes by these normal components will be calculated as a function of time during STORM-FEST periods for: (i) 6-h NWS-only soundings; (ii) 3-h NWS-only soundings; (iii) 6-h NWS plus special site soundings; and (iv) 3-h NWS plus special site soundings. An increase in time resolution without an increase in spatial resolution will likely result in a small percentage increase in estimates of the fluxes. Much improved flux estimates are expected when a jet streak or short wave that would be poorly resolved by the NWS stations propagates across the picket fence. A key question will be whether 6-h soundings with higher spatial resolution will be adequate, or whether the time variability in the fluxes requires 3-h soundings. This flux variability may be displayed simply in a time versus north-south distance plot.

It is also of interest to document the atmospheric layers that contribute the majority of the fluxes. Kinetic energy and momentum fluxes will be concentrated at the jet levels. Moisture and heat fluxes may have major contributions at low levels, and may not be well-

resolved by the combination of mountain and valley stations in the picket fence. Nevertheless, these Picket Fence flux calculations will illustrate the different atmospheric layers that any future picket fence of profilers and ground-based remote sensors would have to be able to resolve.

One of the objectives of STORM-FEST is to obtain high temporal resolution observations for testing four-dimensional data assimilation (4DDA) systems for the mesoscale. A complete data impact test would involve comparisons of the picket fence approach and the dropwindsonde approach. The 4DDA systems test will then involve these data impact studies: (i) With and without the additional information from dropwindsondes; (ii) With and without the picket fence soundings; and (iii) the combination of both approaches. Unfortunately, it was not possible to execute the dropwindsonde missions during the first part of STORM-FEST so that only a limited data impact study will be possible using the Picket Fence IOP3 (see Section 3). The 4DDA studies will be carried out in conjunction with Dr. E. Barker of the Naval Research Laboratory in Monterey, California.

The demonstration of a significant impact on the meso-α domain forecasts due to the picket fence boundary values would be an important step for planning of STORM. The forecast experiments will be done in conjunction with Dr. R. Hodur of the Naval Research Laboratory in Monterey, and will be based on the series of 4DDA tests described above. Comparisons will be made with the real-time forecasts where possible. Comparisons of the fluxes across the west coast with and without the additional sites in Table 1 could be used to infer the extra forcing associated with specific phenomena that are planned to be measured with dropwindsondes over the eastern North Pacific during STORM I. It also has implications for future operational weather forecasting in the Midwest USA when a dense network of ground-based remote sensors will have a data-void area upstream over the Pacific.

2. Picket Fence Observations

a. Rawinsonde equipment

Two types of rawinsonde receivers were used at the eight special Picket Fence sites (Table 1). Stations OLM, CGO, RDD, ILA and PRB used a Department of Navy version of the Vaisala Marwin MW-12 system (AN/UMQ-12 Mini-Rawinsonde System), which will be referred to as the MRS. The MRS uses Omega and Sigma navigational aids to track the position of the radiosonde during ascent. The rawinsonde receiver used at NPS was a Vaisala Digicora MW-11 system. The Digicora systems is capable of using either LORAN or Omega and Sigma navigational aids.

Both the MRS and Digicora system used Vaisala RS80-15 radiosondes, which are pre-calibrated and have a perforated paper tape to enter the calibration coefficients. Winds from these two systems are generated by each receiver system according to the steps outlined in Table 2.

Table 2. Steps required to compute winds in the Vaisala rawinsonde system.

1. Phase detection from Navigational Aids.
2. Phase filtering/quality control.
3. Phase derivative computation, that also produces residual variance.
4. Composition of different frequency phase derivatives from one station to produce a single phase derivative corresponding to each particular transmitter.
5. Wind vector computation.
6. Consistency checking.
7. Wind value quality control.

A running buffer of the most recent four minutes for Omega (two minutes for LORAN) of quality-controlled wind values is continuously updated during the sonde ascent. For the first two (Omega) or one (LORAN) minutes of the ascent, winds are extracted at 5 s (Omega) or 10 s (LORAN) intervals using cubic spline interpolations of the east (U) and north (V) components. Although the surface wind observation is utilized in the spline fits, the strong center weighting of the spline fits can lead to discontinuities in the lowest few 100 m, especially if there is strong shear at low altitudes. As newer data are collected, the older samples in the buffer are overwritten and winds are calculated from the

reinterpolated spline fits. The resulting winds for the Omega (LORAN) system are roughly equivalent to 2-min (1-min) radar-tracked rawinsonde winds.

Temperature information from the RS80-15 radiosondes are derived from a silvered bead thermistor. Relative humidity (RH) data are obtained from the Vaisala HUMICAP sensor, which employs a capacitor that is sensitive to RH changes. A silvered hood covers the sensing portion of the HUMICAP to reduce solar heating and deposition of moisture on the sensing surface.

As at the regular NWS, Air Force and Port Hardy sites, the Pacific Missile Test Center at Pt. Mugu, CA (NTD) also uses a radar tracking system that follows the radiosonde during ascent. Winds were computed from the 6-sec elevation and azimuth angles. Data from the NWS and AES sites were received and prepared by the STORM Project Office at NCAR. The Vandenberg sounding data were post-processed at NPS from printouts of data at 200-foot increments.

b. Data acquisition at special sites

Each of the Picket Fence special sites collected processed rawinsonde data with 5 s or 10 s resolution for the duration of each launch. The Vaisala MW-11 and MW-12 systems compute significant and mandatory levels for each launch. During IOPs 1-3, 100 gm balloons were used at the special sites (except NTD), whereas 200 or 300 gm balloons were used during IOP 4. Typical ascent rates for the 100 gm balloon rawinsondes were 3-4 m/s. Ascent rates for the larger balloons were 4-6 m/s.

Rawinsonde data were collected via serial line to a personal computer (PC). Each special site also employed a serial printer as backup to the PC. Hard copies of the significant and mandatory levels were made after each launch to insure that at least significant and mandatory levels could be recovered in the event of a PC or operator error.

c. Post-processing of rawinsondes

Upon receipt of the data files from each site, vertical plots of the measured variables were generated. These plots allowed a quick look for any problems in the

soundings. Surface observations from each of the soundings were tabulated and checked for launch to launch consistency. Surface observations were recorded at several of the special sites from readouts of the radiosonde prior to the launch. Anomalous surface observations and the steps taken to correct these values are described below in the analysis summaries for each site.

All rawinsonde data from the special sites were converted to a common format and passed through a quality-control procedure (Baker 1991) that checked each sounding for hydrostatic consistency and vertical wind shear. Levels that were flagged as having erroneous geopotential heights were recomputed, and those winds that were flagged as suspect were changed to missing. Layers that were found to be slightly super-adiabatic were not corrected.

d. **Data formats**

The Picket Fence rawinsonde data base has been converted into the First GARP Global Experiment (FGGE) format (Table 3). The references to tables in the remarks column refer to the notes in the FGGE code.

A second data base has been created by interpolating the observations to 10 mb intervals. An algorithm was developed to search in the rawinsonde record for the nearest levels with data above and below each 10 mb interpolation level. These adjacent levels had to be within 50 mb of the desired 10 mb interpolation level, or that level was recorded as missing. If this interval criterion was satisfied both above and below the level, a logarithmic pressure interpolation was utilized.

TABLE 3. Upper-air format.

a) Report Identification

Parameter	No. of chars.	Position number	Units	Remarks
Unique report identifier	1	1		Unique character = '*'
Data source index	2	2-3		See Table A7
Block station number	5	4-8		
Elevation	4	9-12	meters	
Latitude	5	13-17	deg. and hundreths	+=North -=South
Longitude	5	18-22	deg. and hundreths	0.00 to 359.99 (E-W)
Instrument type	2	23-24		Set to '99'
Year	2	25-26		90=1990
Month	2	27-28		01-12=Jan-Dec
Day	2	29-30		01-31
Hour	2	31-32		00-23 UTC
Mintues	2	33-34		00-59
No. of logical records (levels)	3	35-37		Variable number

TABLE 3 (continued)

b) Upper-air level data record

Parameter	No. of chars.	Position number	Units	Remark
Type of level	2	1-2		See Table A8
Pressure	5	3-7	10 mb	
Height	5	8-12	gpm	+=above sea level -=below sea level
Quality control: height[1]	2	13-14		See Table A9
Temperature	4	15-18	10^{-1} °C	
Quality control: temperature[1]	2	19-20		See Table A9
Dew-pt depression	4	21-24	10^{-1} °C	
Quality control: Dew-pt. depression[1]	2	25-26		See Table A9
Wind direction	3	27-29	deg.	
Wind speed	3	30-32	ms^{-1}	
Quality control: wind[1]	2	33-34		See Table A9
Record number	3	35-37		Level number within the report

[1]Two positions are reserved for the quality control flags applied to upper-air data. The first position, which is reserved for results of the horizontal checks, is not used for the Picket Fence data. The second position contains the results of the internal quality checks.

3. STATION SUMMARIES

a. Port Hardy, BC (YZT)

Rawinsondes from the Canadian AES station YZT were received from NCAR in their CLASS format with data at 10 mb increments to the 100 mb level. These soundings had been passed through a similar quality control procedure as in Section 2c at NCAR before being sent to NPS. Table 4 is a list of launch times, minimum pressure or maximum altitude achieved in the sounding, and any special notes related to each launch. Wind vectors overlaid with contours of potential temperatures from each launch are provided in Fig. 3 for each of the four Picket Fence Intensive Observing Periods (IOP).

Table 4 Summary of rawinsonde launches from Port Hardy (YZT)

Date	Time	Min. Press	Max. Alt.	Notes
02/13	0600	56.2	19769	
02/13	0900	49.6	20572	
02/13	1158	18.9	26934	
02/13	1456	61.1	19153	
02/13	1754	35.7	22691	Data only to 210 mb.
02/14	1800	49.5	20592	
02/14	2101	43.2	21475	Data only to 140 mb.
02/15	0001	11.0	30575	
02/15	0300	49.0	20665	
02/15	0602	102.6	15824	
02/15	0901	38.1	22332	
02/15	1200	38.4	22280	
02/15	1500	59.6	19342	
02/15	1800	37.7	22401	
02/15	2100	37.3	22484	
02/16	0007	10.3	30911	Data only to 220 mb.
02/16	0301	35.5	21117	
02/16	0601	53.8	20075	Data only to 220 mb.
02/16	0901	41.0	21871	Data only to 210 mb.
02/16	1201	10.4	30779	
02/16	1500	-----	-----	No launch recorded.
02/16	1800	-----	-----	No launch recorded.
02/20	0030	76.9	17737	Second release.
02/20	0300	48.1	20789	Data only to 180 mb.
02/20	0601	44.6	21284	Data only to 180 mb.
02/20	0900	44.4	21316	Data only to 130 mb.
02/20	1200	9.5	31308	
02/20	1500	38.9	22056	
02/20	1800	36.5	22507	
02/20	2100	33.4	23100	Data only to 200 mb.
02/21	0001	11.2	30255	
03/05	1200	-----	-----	No launch recorded.
03/05	1500	63.3	18949	Data only to 190 mb.
03/05	1800	42.9	21495	Data only to 210 mb.
03/05	2102	41.3	21766	
03/06	0002	15.4	28125	
03/06	0300	46.0	21058	
03/06	0559	34.3	22970	
03/06	0900	37.4	22418	
03/06	1200	8.2	32137	
03/06	1500	38.8	22099	
03/06	1801	49.2	20638	
03/06	2122	19.2	26708	
03/07	0000	17.0	27486	Data missing from NCAR.
03/07	0300	30.0	23840	Data missing from NCAR.
03/07	0600	27.1	24503	Data missing from NCAR.
03/07	0900	78.0	17709	Data missing from NCAR.
03/07	1200	15.9	27916	Data missing from NCAR.

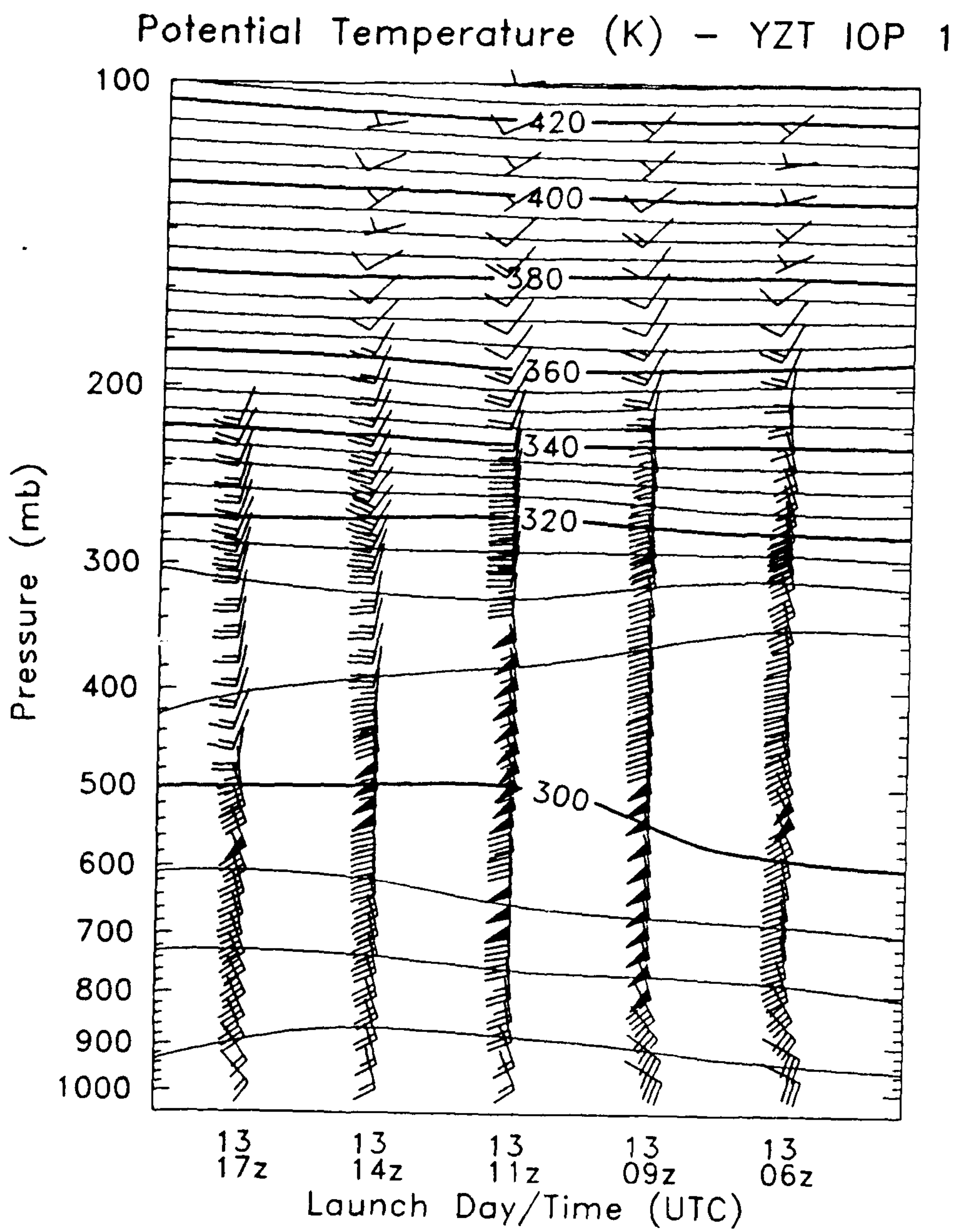

Fig. 3 **Wind vectors (long barb is 10 kt, 5 m/s) and potential temperatures (K) during Intensive Observing Periods: (a) 1; (b) 2; (c) 3; and (d) 4 for Port Hardy (YZT).**

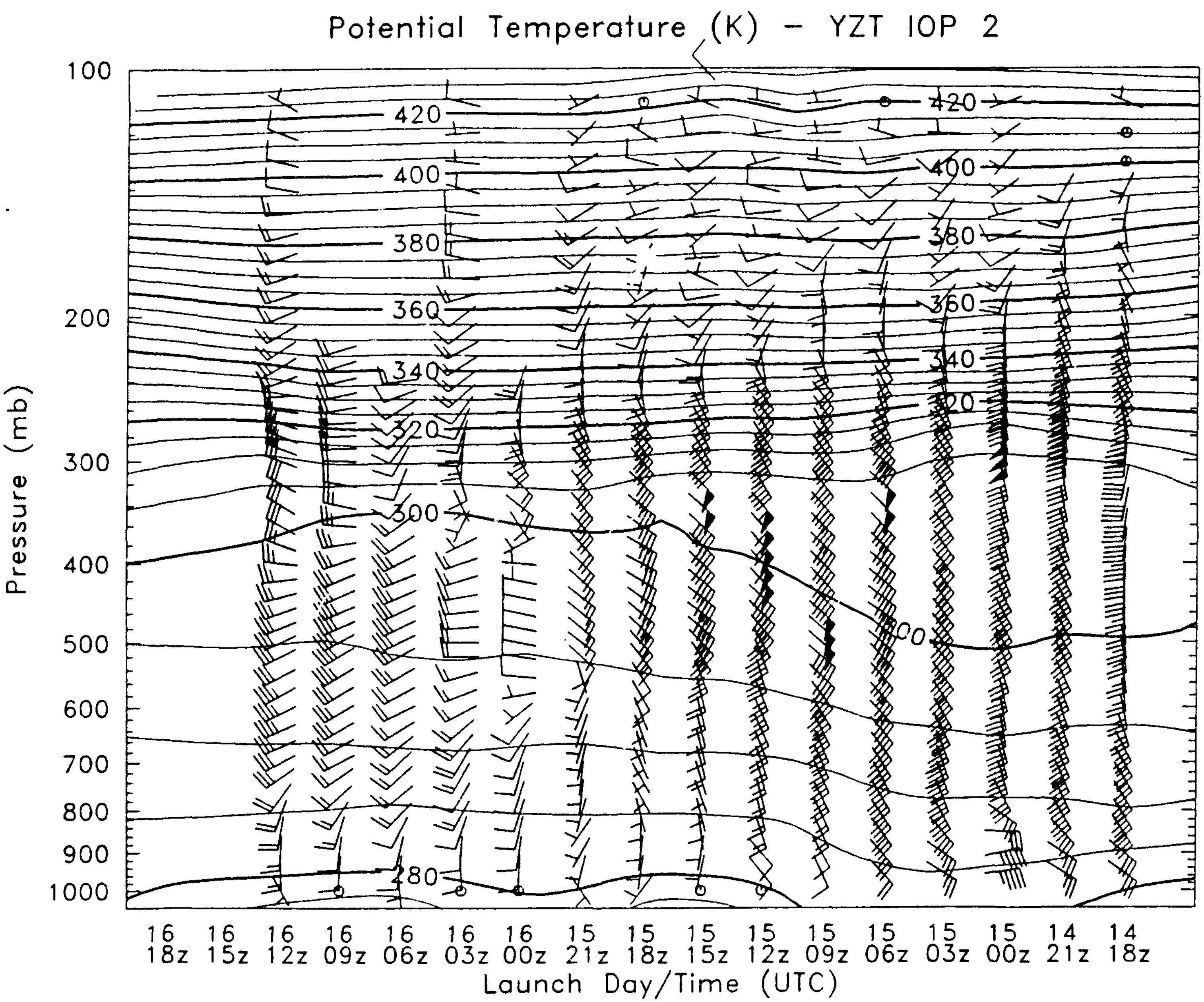

Fig. 3 Wind vectors (long barb is 10 kt, 5 m/s) and potential temperatures (K) during Intensive Observing Periods: (a) 1; (b) 2; (c) 3; and (d) 4 for Port Hardy (YZT).

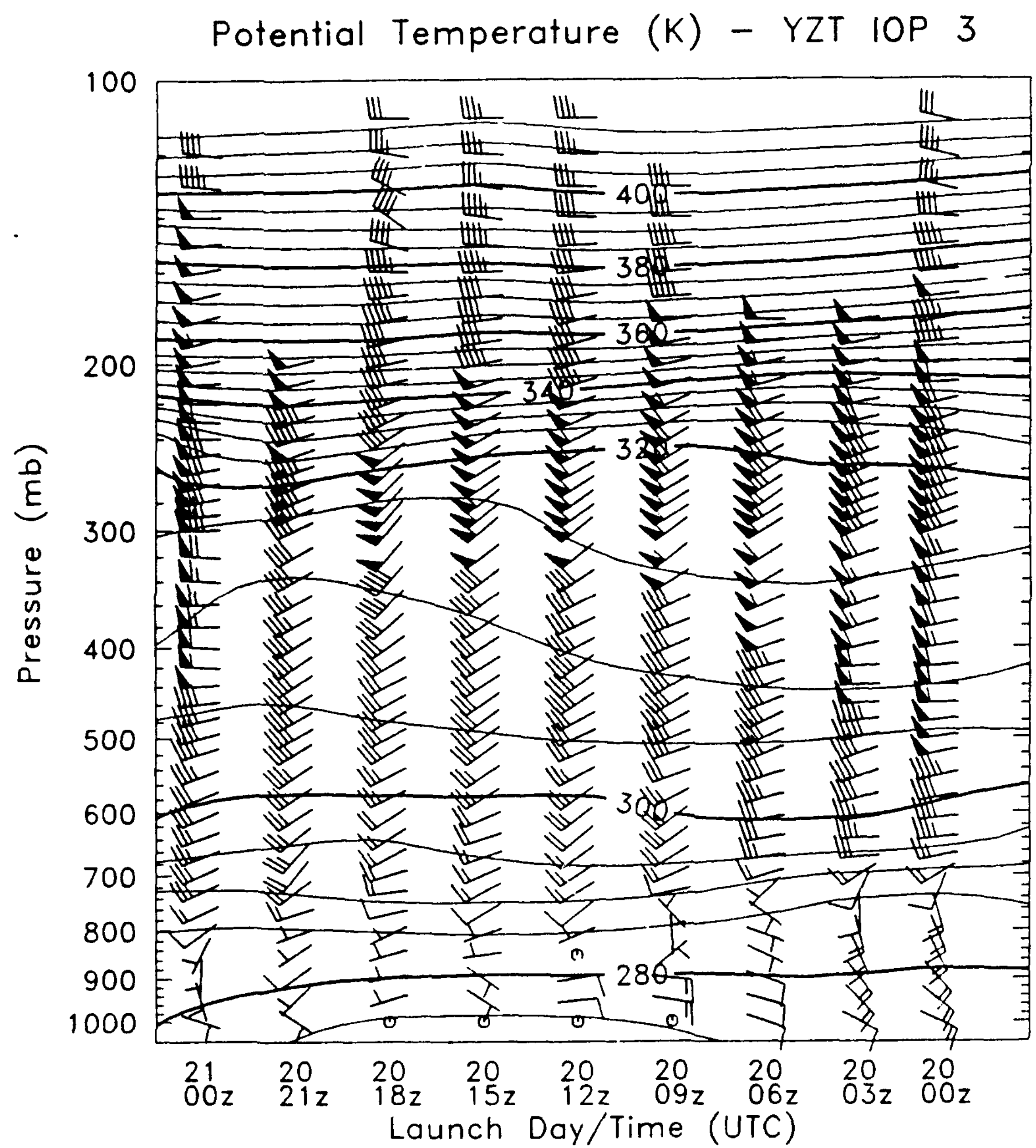

Fig. 3 Wind vectors (long barb is 10 kt, 5 m/s) and potential temperatures (K) during Intensive Observing Periods: (a) 1; (b) 2; (c) 3; and (d) 4 for Port Hardy (YZT).

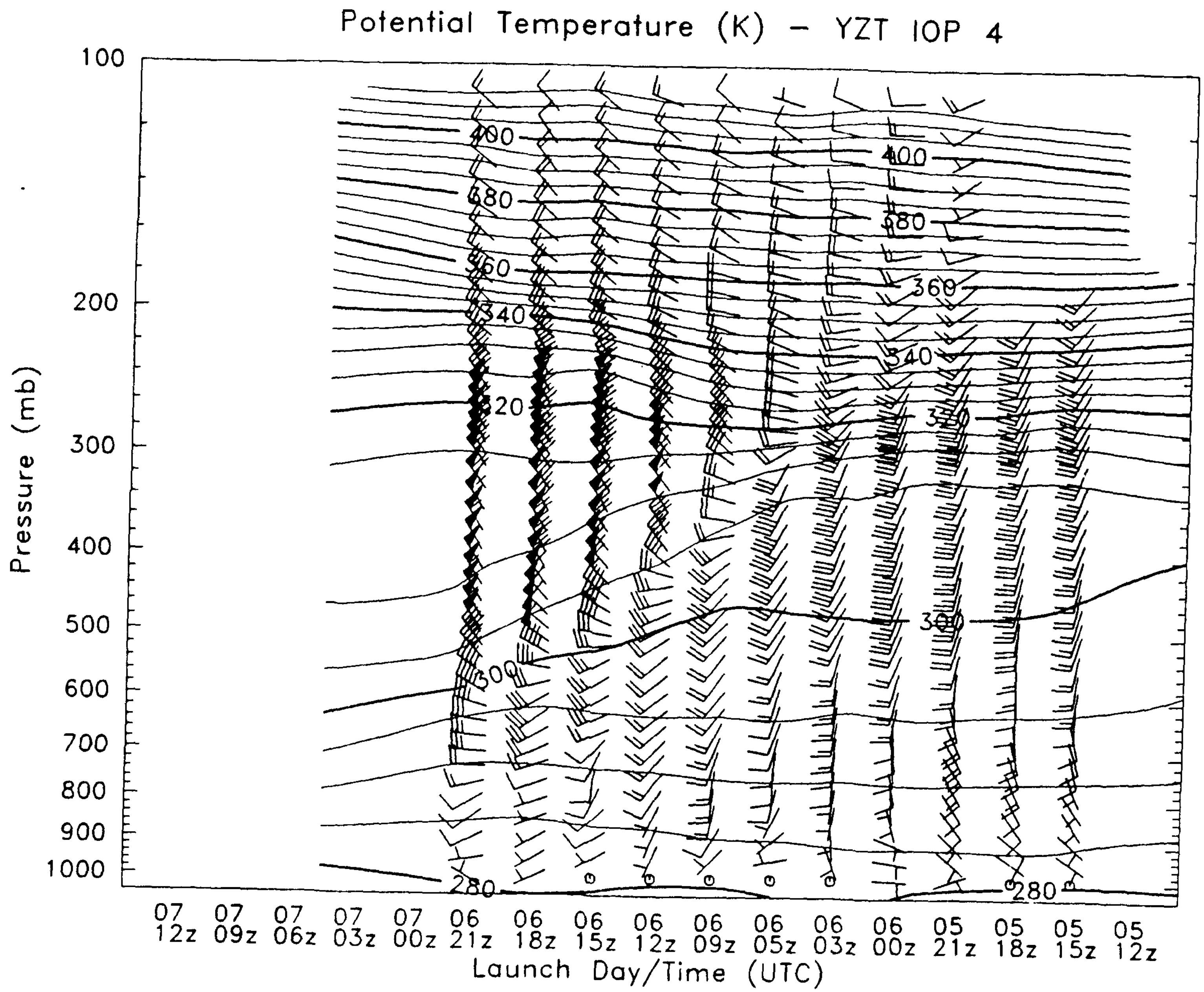

Fig. 3 Wind vectors (long barb is 10 kt, 5 m/s) and potential temperatures (K) during Intensive Observing Periods: (a) 1; (b) 2; (c) 3; and (d) 4 for Port Hardy (YZT).

b. **Quillayute, WA (UIL)**

Soundings from the NWS station at Quillayute were also processed by NCAR. Table 5 is a list of launch times, maximum altitudes reached and special notes related to each launch. Wind vectors and contours of potential temperature for each of the four Picket Fence IOPs are presented in Fig. 4.

Table 5 Summary of rawinsonde launches from Quillayute (UIL)

Summary of Rawinsonde Launches from UIL:

Date	Time	Max. Alt.	Notes
02/13	0509	21932	
02/13	0813	17910	
02/13	1112	22277	
02/13	1410	21942	Edited.
02/13	1706	11505	Bad sonde. NCAR data to 110 mb?
02/14	1708	23826	
02/14	2004	23421	
02/14	2306	17754	
02/15	0201	16490	
02/15	0504	8830	Weak signal.
02/15	0807	15455	Edited.
02/15	1103	20422	
02/15	1405	22550	
02/15	1704	21429	Edited.
02/15	2004	21875	
02/15	2359	32066	Second release.
02/16	0300	-----	No launch recorded, equip. problem.
02/16	0505	19045	
02/16	0804	22621	
02/16	1103	21805	
02/16	1404	20457	
02/16	1709	24548	Skipped pressure contact 87.
02/19	2314	27357	
02/20	0207	10410	Pressure sensor failure.
02/20	0511	17302	
02/20	0814	19206	Antenna lock-up: Mins 18.4-19.7.
02/20	1104	16052	
02/20	1411	20049	
02/20	1705	23900	
02/20	2005	22690	
02/21	0000	21286	Second release. No data from NCAR.
03/05	1106	13962	
03/05	1500	-----	No launch.
03/05	1800	-----	No launch.
03/05	2100	-----	No launch.
03/05	2306	14220	Weak signal/edited.
03/06	0208	16502	Pressure sensor failed/edited.
03/06	0508	24494	
03/06	0810	17504	
03/06	1108	15007	
03/06	1409	23152	Edited.
03/06	1700	21982	Edited.
03/06	2002	21147	Edited.
03/06	2304	30498	Skipped press. contacts 163-165.
03/07	0203	23201	
03/07	0600	15811	Second release/edited.
03/07	0817	19415	Edited.
03/07	1105	17776	

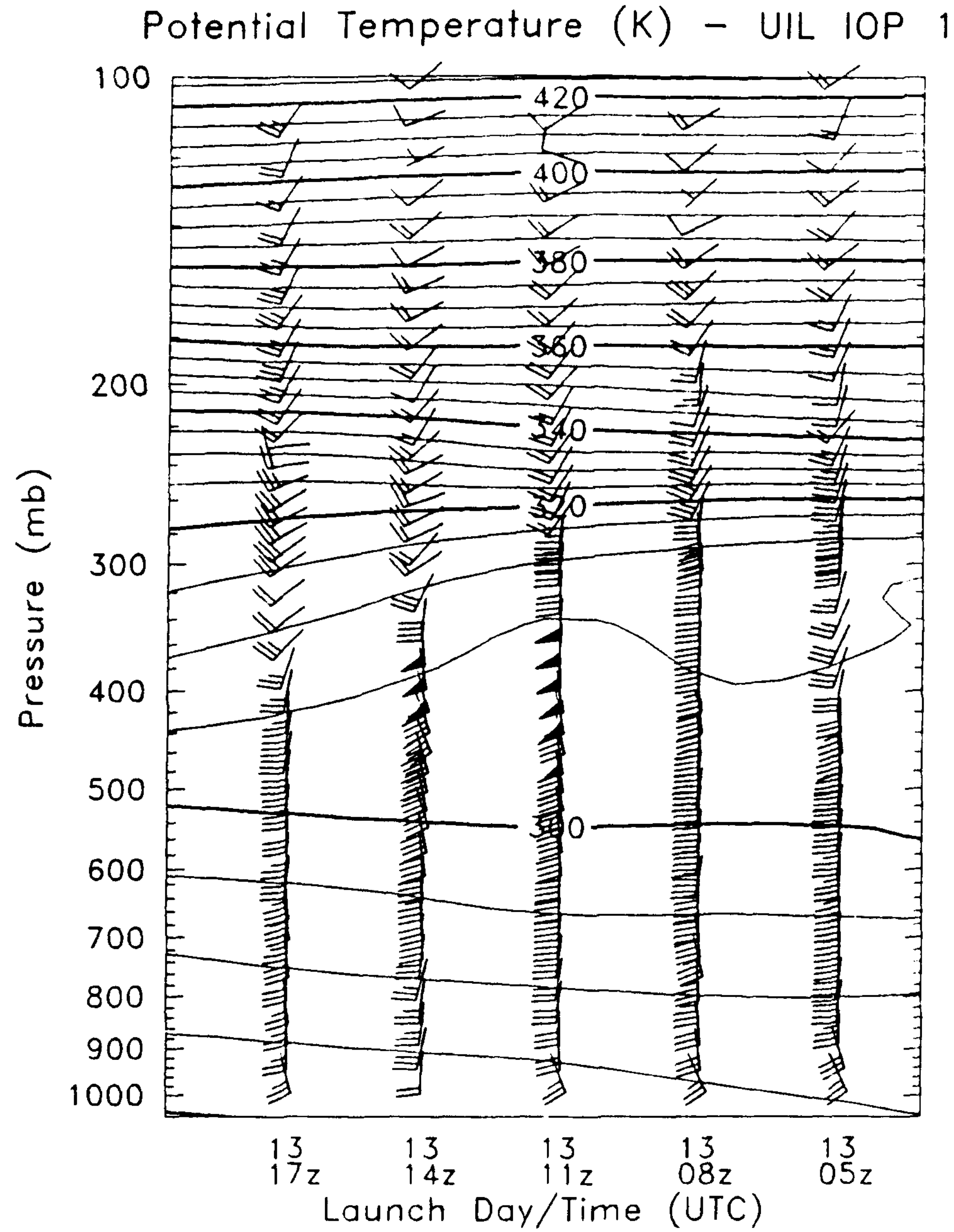

Fig. 4 As in Fig. 3, except for Quillayute (UIL).

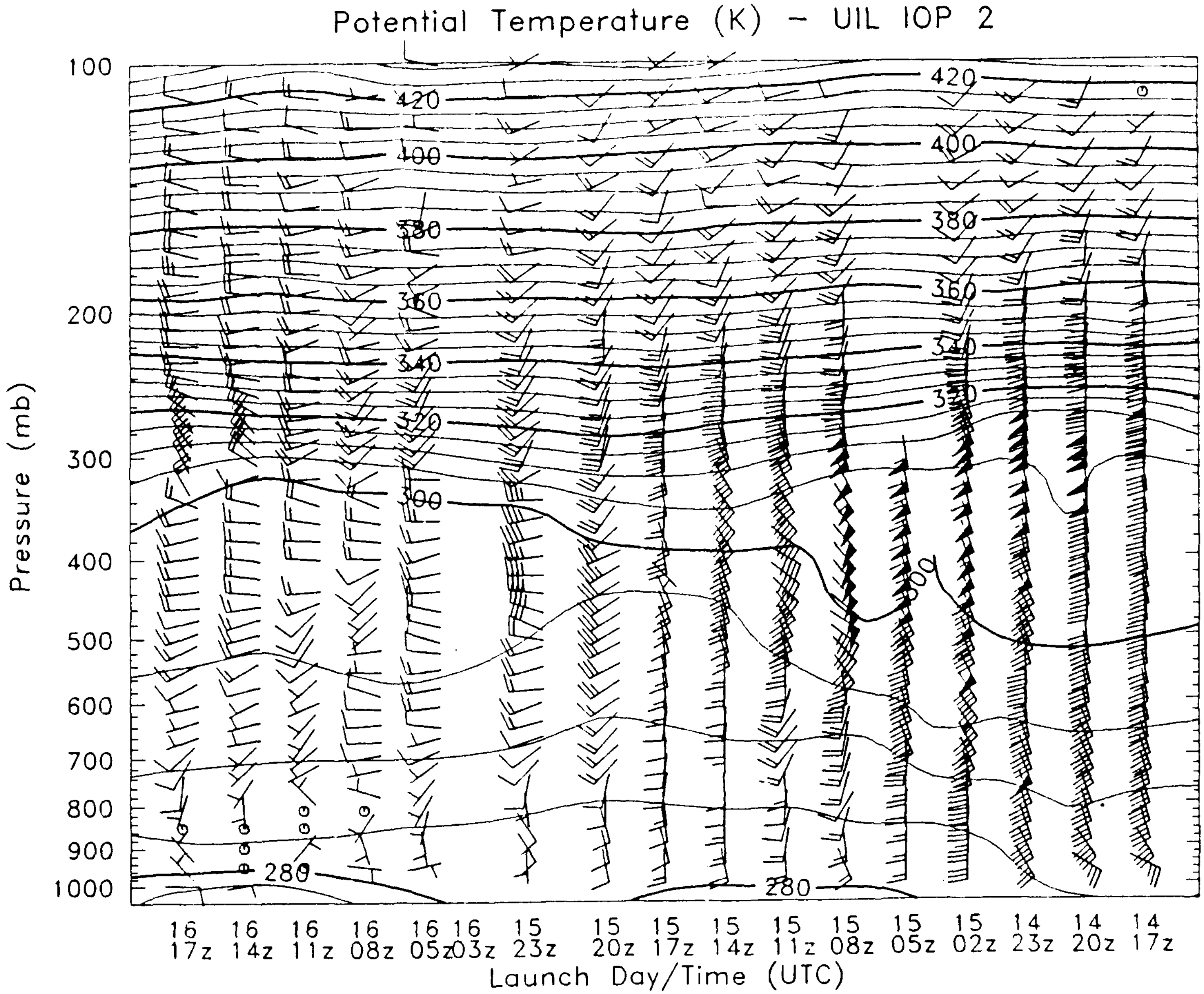

Fig. 4 As in Fig. 3, except for Quillayute (UIL).

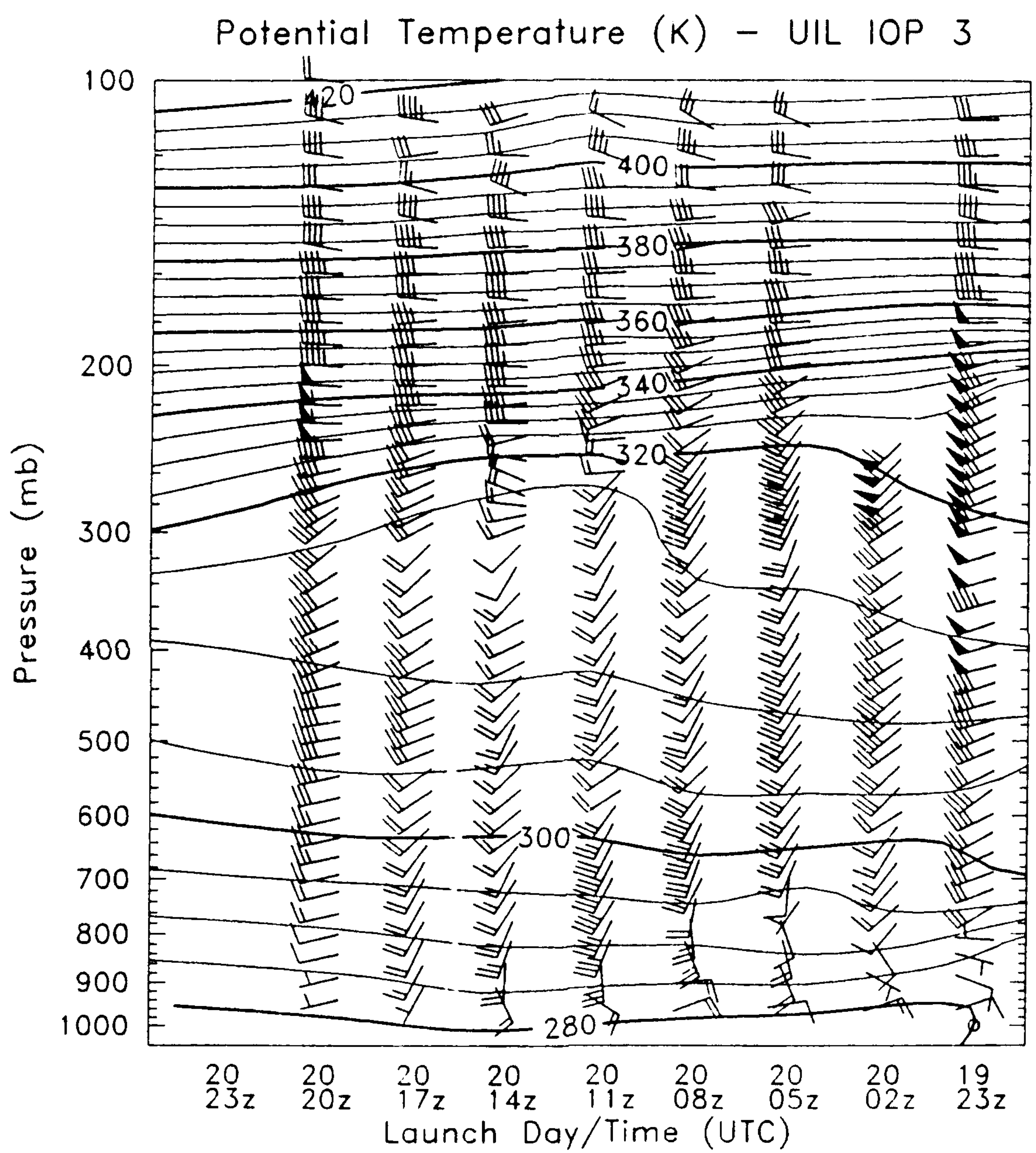

Fig. 4 As in Fig. 3, except for Quillayute (UIL).

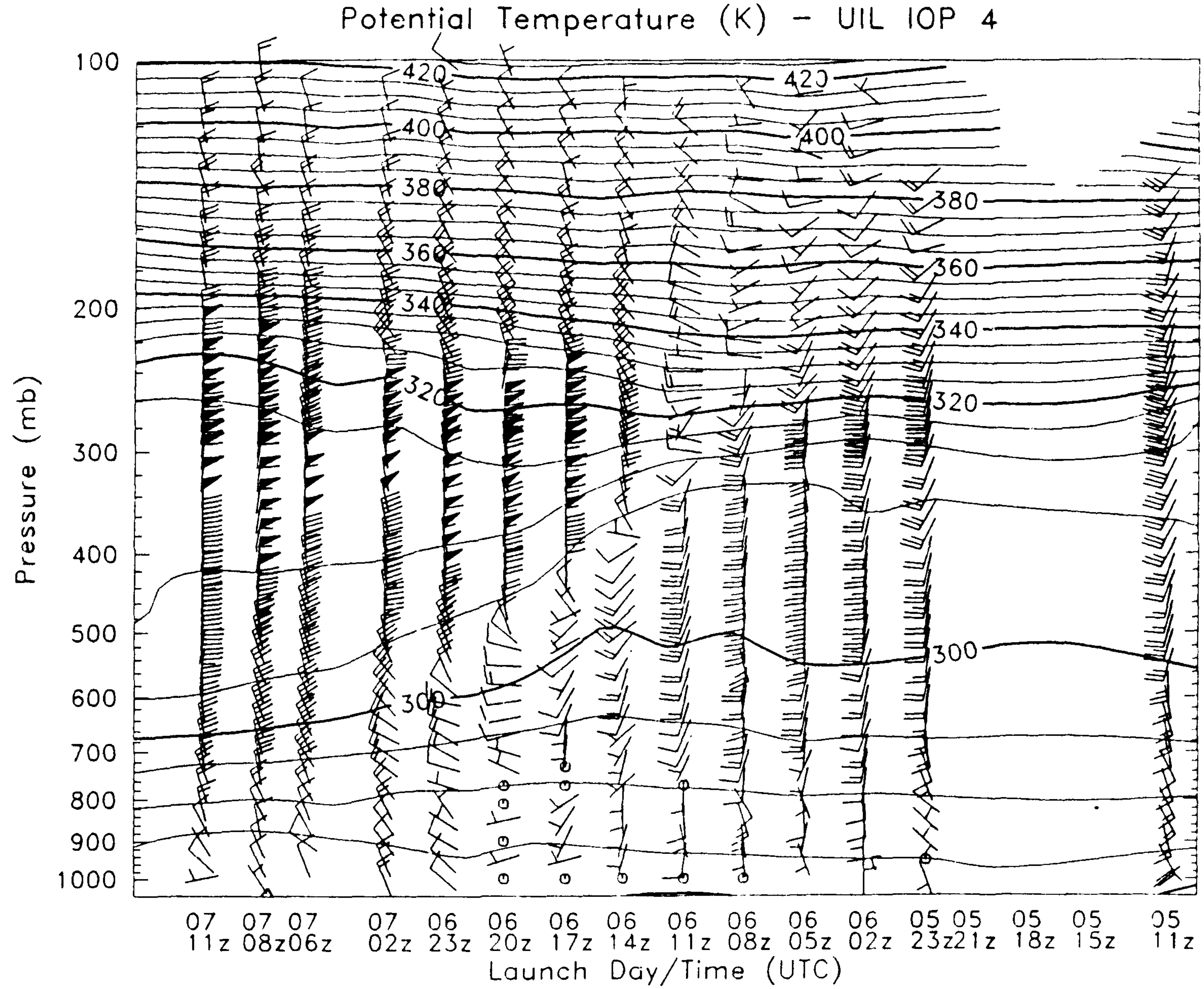

Fig. 4 As in Fig. 3, except for Quillayute (UIL).

c. Olympia, WA (OLM)

The Mini-Rawinsonde System (MRS) soundings from the Special Picket Fence site at the NWS office at the Olympia airport were processed at NPS. The launch team consisted of four volunteers from the University of Washington and two from Submarine Group 9, based in Bremerton, WA. Surface observations were taken from the OLM NWS office readouts. On some occasions, the launch notes indicated that sea-level pressure, instead of station pressure, had been manually entered into the MRS. Since the OLM launch site is at 59 m above mean sea level, a correction was required. The plots of MRS pressure readouts against time showed that the MRS utilized the manually entered surface value for about 20-90 seconds, and then radiosonde pressures were used. These traces of pressure versus time showed the point at which pressure values could be believed. Since the transition between the erroneous surface pressure and the more correct sonde pressure was not recoverable, data within this transition period were reported as missing. All geopotential heights were recomputed once the correct station pressure was entered.

Table 6 is a list of launch dates and times, minimum pressure level or maximum altitude reached, and notes related to each launch. Winds from each launch overlaid with contours of potential temperature are shown in Fig. 5 for each Picket Fence IOP.

Table 6 Summary of rawinsonde launches from Olympia (OLM)

Date	Time	Min. Press	Max. Alt.	Notes
02/13	0509	145.4	13592	
02/13	0800	415.4	6750	
02/13	1128	218.6	10921	Re-launch, 1st iced.
02/13	1353	826.7	1577	Balloon iced.
02/13	1702	115.3	15100	
02/14	1700	107.9	15519	
02/14	1956	118.0	14929	
02/14	2254	93.9	16400	
02/15	0213	248.1	10070	Only SIG & MAND to 606 mb
02/15	0637	184.6	11963	Re-launch, 1st iced.
02/15	0801	224.0	10698	
02/15	1104	184.1	11971	
02/15	1404	162.8	12775	
02/15	1701	106.5	15566	
02/15	1959	125.5	14496	
02/15	2304	141.1	13710	
02/16	0159	147.3	13446	
02/16	0458	146.6	13475	
02/16	0756	157.1	13012	
02/16	1052	201.3	11390	
02/16	1500	-----	-----	No launch recorded.
02/16	1800	-----	-----	No launch recorded.
02/20	0000	-----	-----	No launch recorded.
02/20	0157	274.7	9673	No Winds.
02/20	0600	-----	-----	No launch recorded.
02/20	0828	207.8	11371	2nd balloon.
02/20	1106	221.6	10951	
02/20	1402	199.3	11638	
02/20	1713	126.0	14625	
02/20	1947	99.9	16120	
02/20	2256	189.5	11996	Corr. sfc. p, 50 mb high.
03/05	1133	27.7	24259	
03/05	1425	22.0	25762	
03/05	1727	212.8	11160	
03/05	2124	34.7	22833	
03/06	0000	-----	-----	No launch recorded.
03/06	0230	61.0	19218	No winds 917-596 mb.
03/06	0529	96.0	16292	
03/06	0832	59.0	19432	
03/06	1152	32.2	23316	2nd balloon.
03/06	1423	63.7	18938	
03/06	1722	89.5	16783	SIG and MAND up to 530.
03/06	2018	739.5	2570	Balloon iced, no relaunch
03/06	2256	68.5	18519	
03/07	0203	98.1	16172	
03/07	0512	83.0	17271	SIG and MAND levels only.
03/07	0753	149.1	13516	
03/07	1200	-----	-----	No launch recorded.

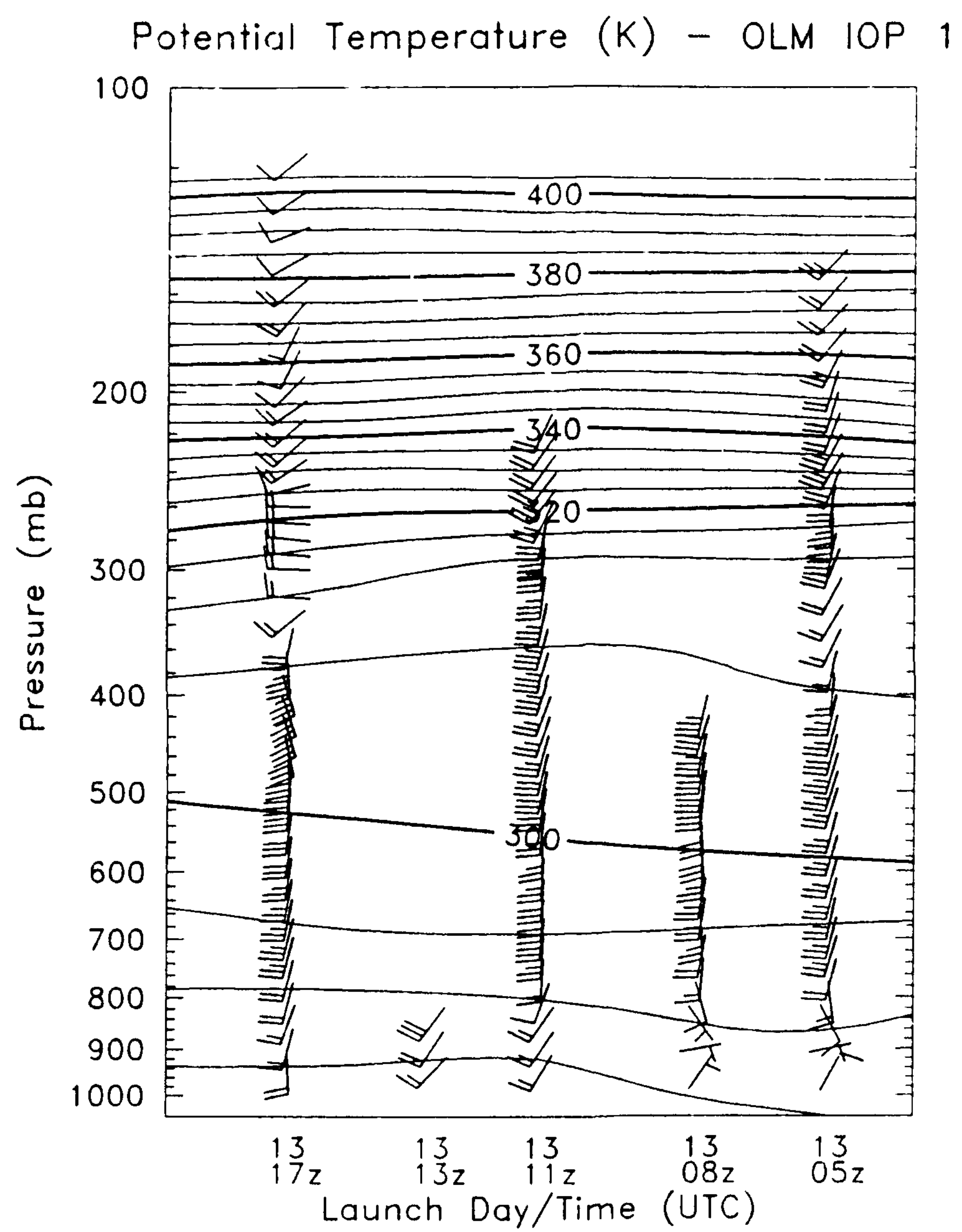

Fig. 5 As in Fig. 3, except for Olympia (OLM).

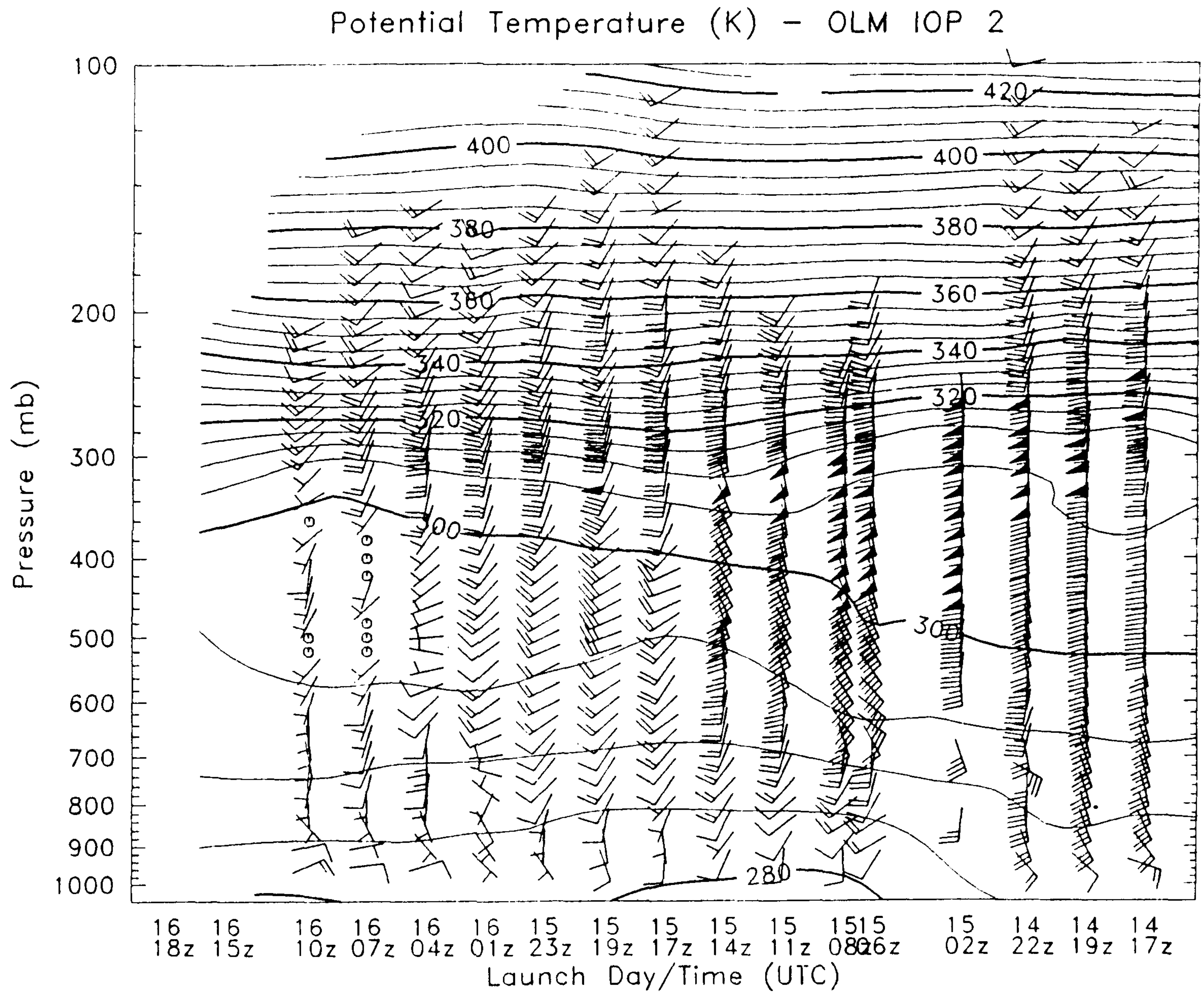

Fig. 5 As in Fig. 3, except for Olympia (OLM).

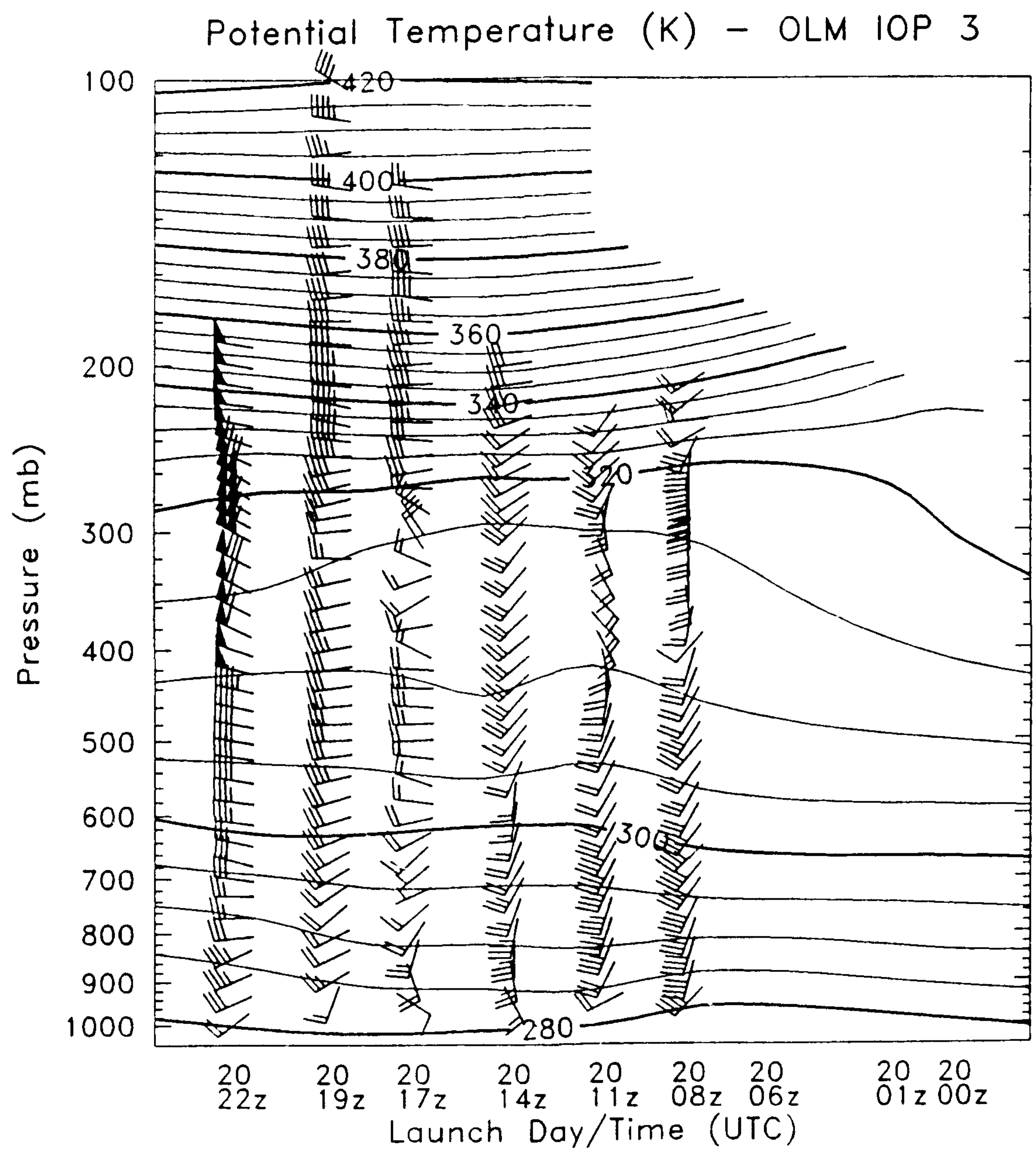

Fig. 5 As in Fig. 3, except for Olympia (OLM).

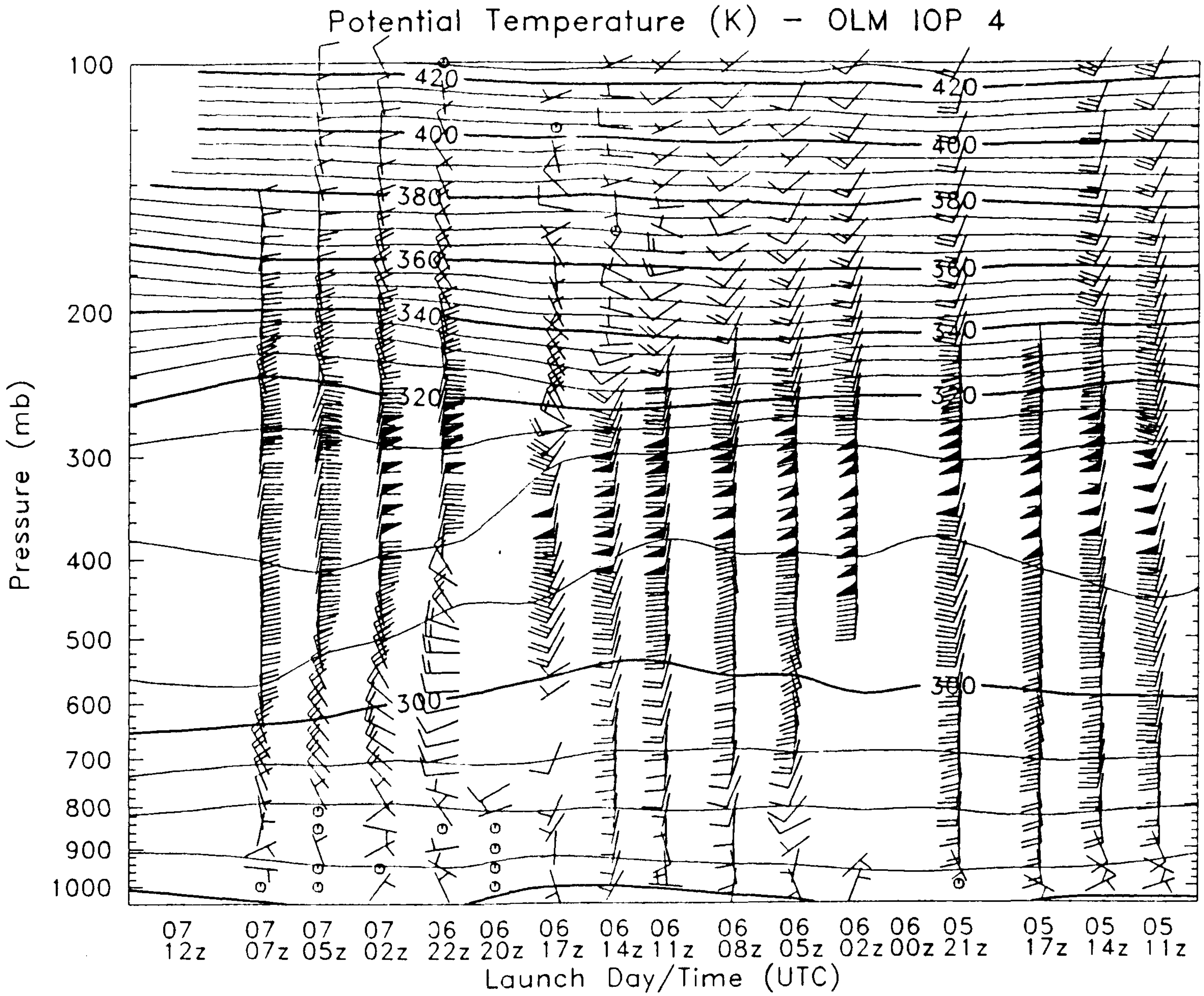

Fig. 5 As in Fig. 3, except for Olympia (OLM).

d. **Salem, OR (SLE)**

Soundings from the regular NWS site at Salem were also processed by NCAR. Table 7 is a list of launch times, maximum altitudes reached and special notes related to each launch. Wind vectors and contours of potential temperature for each Picket Fence IOP are presented in Fig. 6.

Table 7 Summary of rawinsonde launches from Salem (SLE)

Date	Time	Max. Alt.	Notes
02/13	0512	20573	Two balloons.
02/13	0914	9835	Second release.
02/13	1101	15289	
02/13	1401	25083	
02/13	1701	21199	
02/14	1701	24642	
02/14	2000	19036	
02/15	2300	32578	
02/15	0201	17751	
02/15	0512	19456	
02/15	0804	19649	
02/15	1100	23284	
02/15	1404	18457	
02/15	1705	21094	
02/15	2005	21761	
02/15	2302	32764	
02/16	0202	13480	Pressure sensor failure.
02/16	0503	20229	
02/16	0802	20859	
02/16	1103	18883	
02/16	1500	-----	No launch recorded.
02/16	1701	19862	
02/19	2302	28755	
02/20	0231	2948	Iced up. Second release.
02/20	0501	19104	
02/20	0800	27856	
02/20	1102	11816	
02/20	1404	2051	Iced up.
02/20	1703	23317	
02/20	2002	24066	
02/20	2302	19822	
03/05	1105	31390	
03/05	1500	-----	No launch recorded.
03/05	1800	-----	No launch recorded.
03/05	2100	-----	No launch recorded.
03/05	2304	29741	Floating balloon.
03/06	0202	28883	
03/06	0500	10213	
03/06	0807	20537	
03/06	1104	31266	
03/06	1401	24957	
03/06	1700	25167	
03/06	2002	22151	
03/06	2301	29862	
03/07	0201	22159	
03/07	0504	14955	
03/07	0802	17538	
03/07	1101	32293	
03/07	1403	23036	Extra launch.

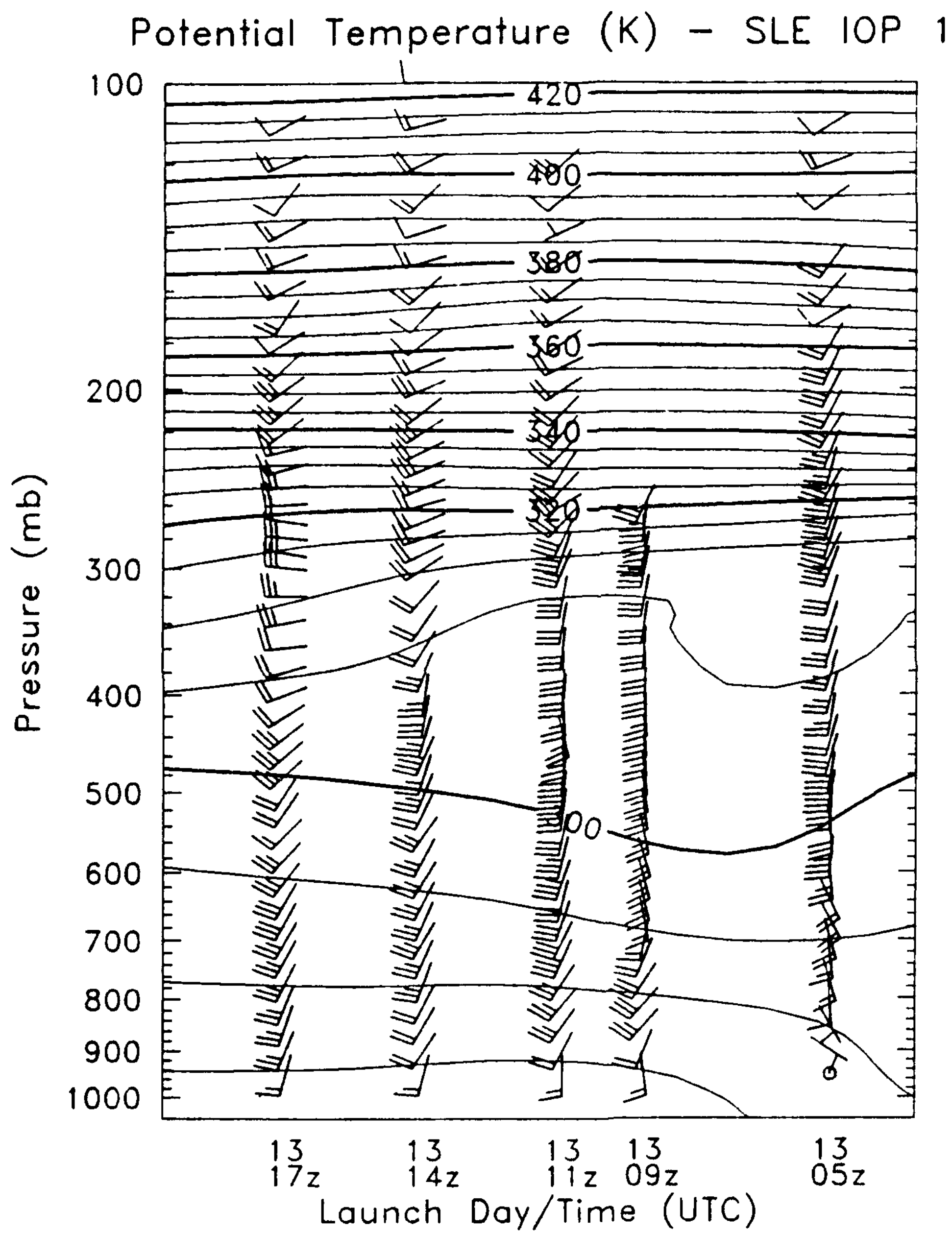

Fig. 6 As in Fig. 3, except for Salem (SLE).

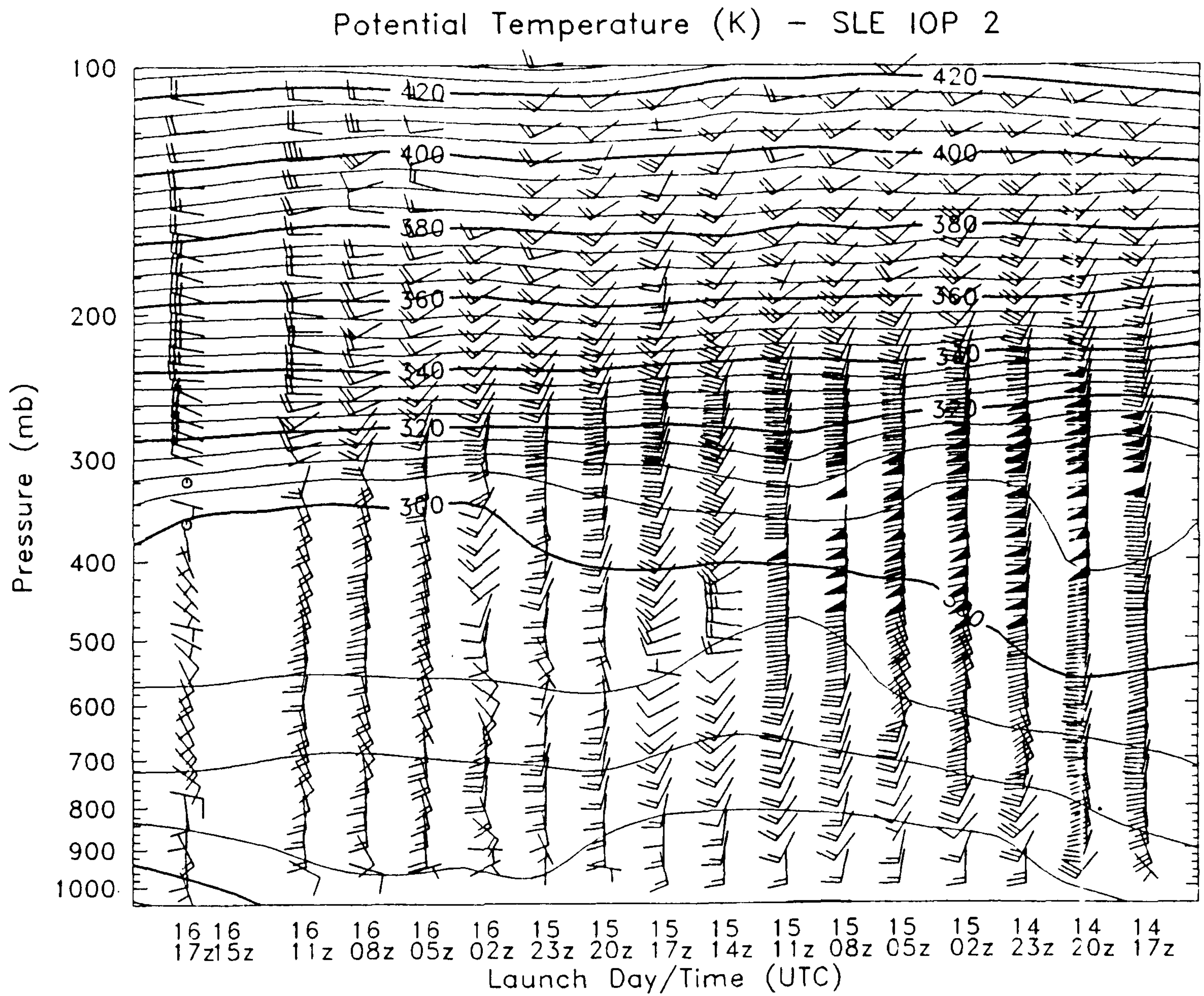

Fig. 6 As in Fig. 3, except for Salem (SLE).

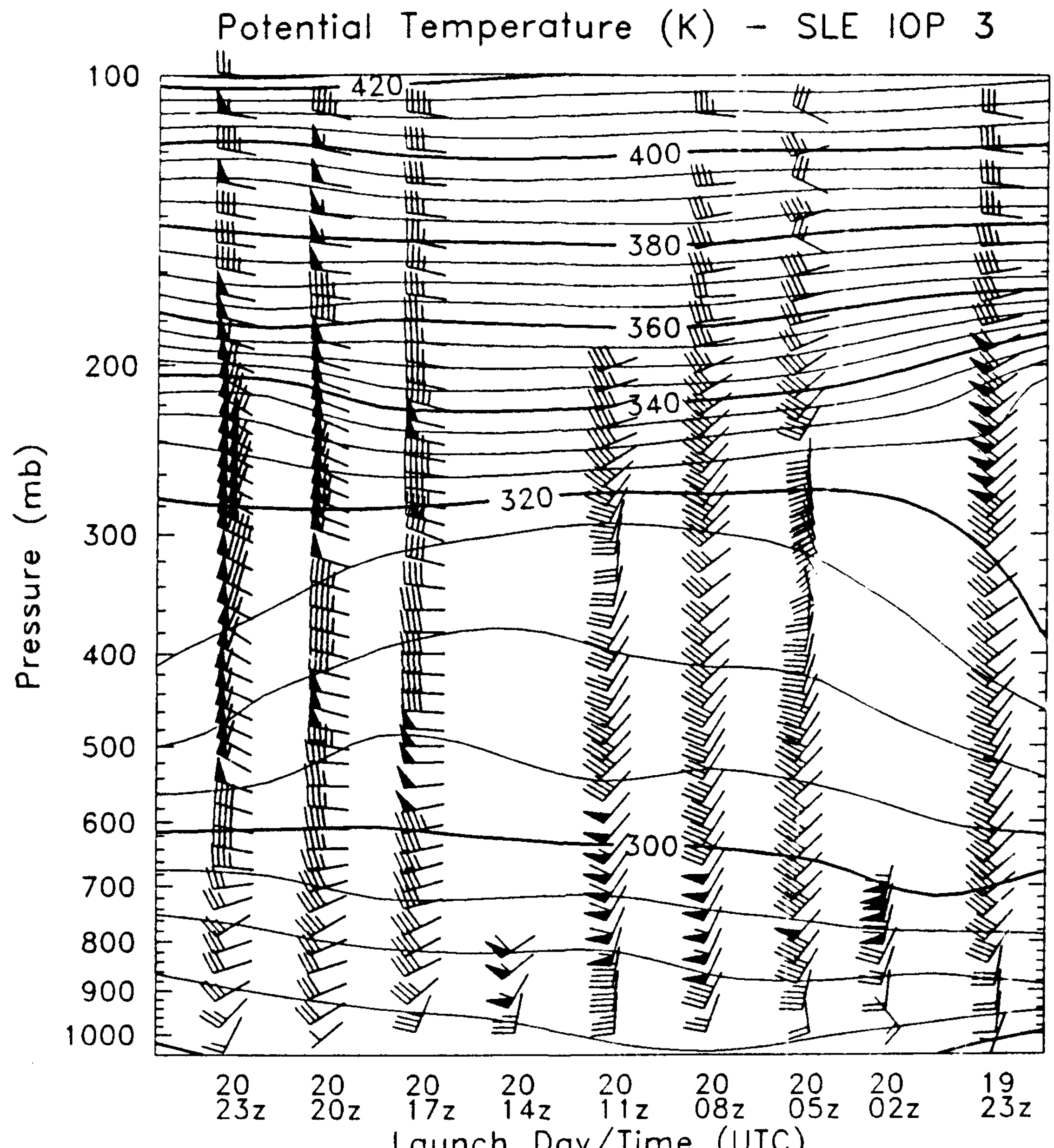

Fig. 6 As in Fig. 3, except for Salem (SLE).

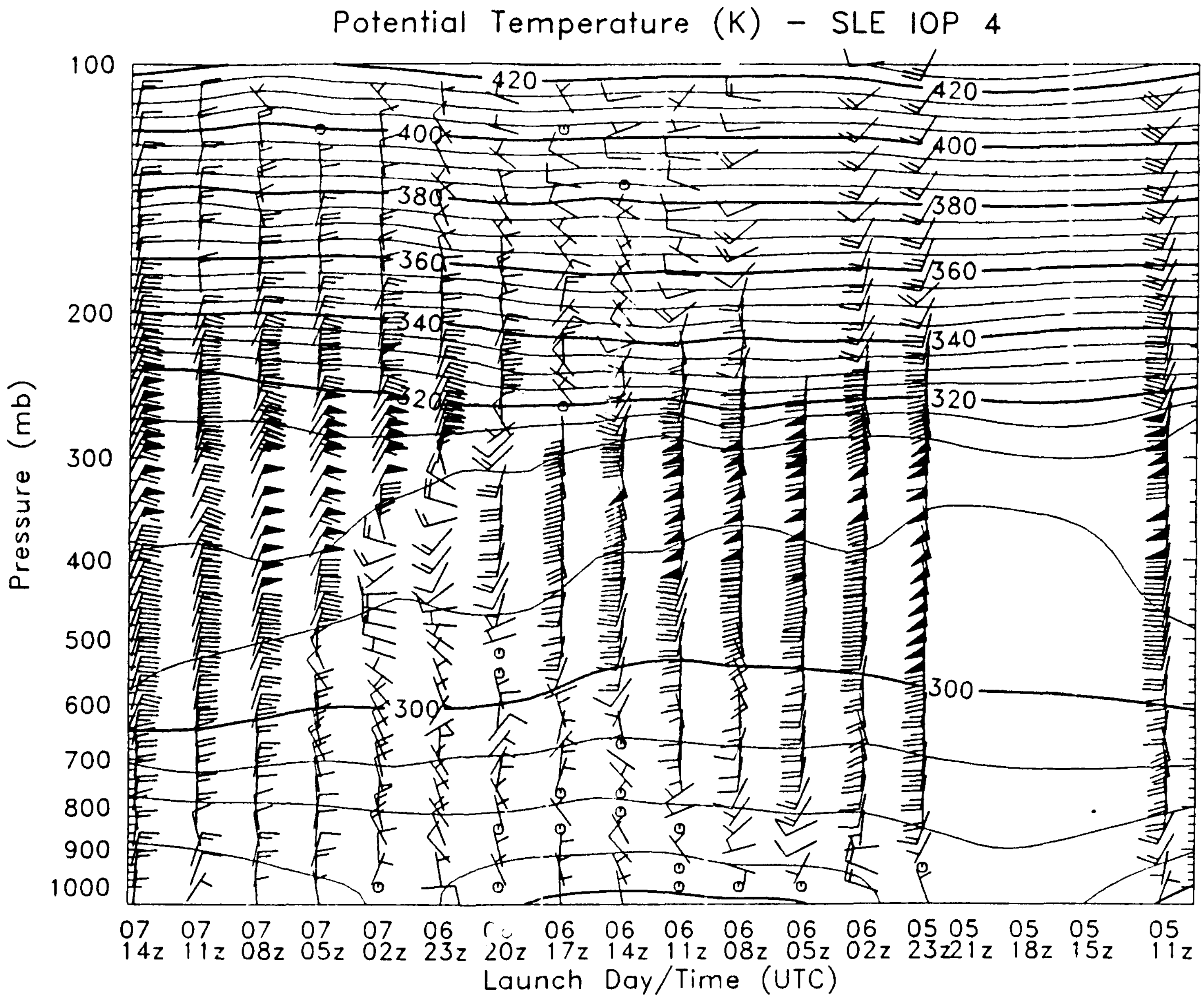

Fig. 6 As in Fig. 3, except for Salem (SLE).

e. **Cottage Grove, OR (CGO)**

Launches at the special Picket Fence site at Cottage Grove, OR were made by a team from the Atmospheric Sciences Department at Oregon State University. Surface pressure values required correction for nearly every launch because of a faulty barometer that was used as a reference. Correct surface pressures were somewhat subjectively obtained by extrapolating plots of sonde pressure versus time to the surface. The nearest reporting NWS site was at Eugene, OR, which is approximately 50 km to the north. Trends in the extrapolated surface pressures compared favorably with pressure trends reported at Eugene. Geopotential heights were recomputed with the corrected surface pressure. Data in the transition region (between the surface and the point where sonde pressures were deemed valid) were reported as missing.

Table 8 is a list of launch dates and times, minimum pressure level or maximum altitude reached, and notes related to each launch. Wind vectors from each launch overlaid with contours of potential temperature are given in Fig. 7 for each Picket Fence IOP.

Table 8 Summary of rawinsonde launches from Cottage Grove(CGO)

Date	Time	Min. Press.	Max. Alt.	Notes
02/13	0600	-----	-----	No launch
02/13	0757	848.0	1379	Balloon iced, no relaunch
02/13	1057	756.2	2294	Balloon iced, no relaunch
02/13	1405	166.3	12696	
02/13	1653	83.5	17167	
02/14	1655	104.4	15720	
02/14	1954	108.5	15452	
02/14	2320	134.1	14074	
02/15	0155	167.8	12598	
02/15	0456	109.5	15390	
02/15	0801	197.3	11545	
02/15	1105	129.1	14328	
02/15	1411	133.8	14070	
02/15	1704	142.5	13689	
02/15	2004	132.0	14184	
02/15	2305	116.0	15031	
02/16	0203	197.0	11550	No RH above 376 mb.
02/16	0505	139.3	13789	
02/16	0758	168.8	12540	
02/16	1107	184.3	11982	
02/16	1411	184.0	11998	
02/16	1656	94.9	16343	
02/19	2253	129.1	14513	
02/20	0159	147.0	13741	
02/20	0459	167.1	12842	
02/20	0804	156.6	13252	
02/20	1104	176.6	12475	
02/20	1406	554.7	4707	Signal lost, slow ascent.
02/20	1705	203.8	11574	
02/20	2008	108.5	15605	SIG and MAND levels only.
02/20	2312	101.0	16078	SIG and MAND levels only.
03/05	1153	83.0	17241	
03/05	1440	61.4	19166	RH data missing.
03/05	1727	46.0	21026	
03/05	2020	52.7	20148	
03/05	2320	34.7	22858	
03/06	0237	38.9	22117	
03/06	0528	49.2	20628	
03/06	0831	39.7	21967	
03/06	1130	63.4	18971	
03/06	1431	39.9	21941	
03/06	1735	38.2	22248	
03/06	2027	30.7	23665	
03/06	2359	30.3	23726	2nd balloon.
03/07	0259	37.5	22357	2nd, SIG and MAND only.
03/07	0532	33.5	23071	
03/07	0832	40.9	21820	
03/07	1236	55.7	19842	Late launch.

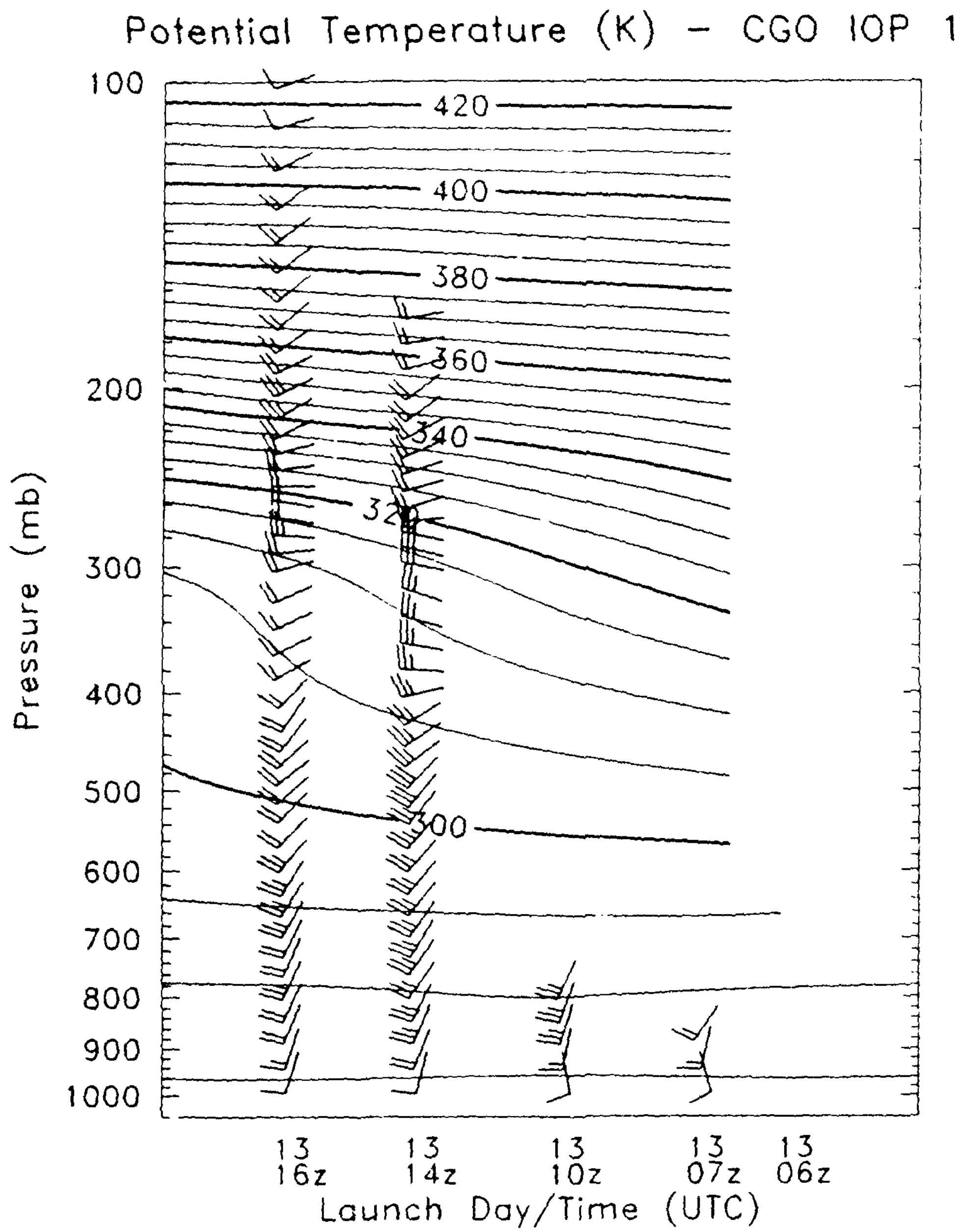

Fig. 7 As in Fig. 3, except for Cottage Grove (CGO).

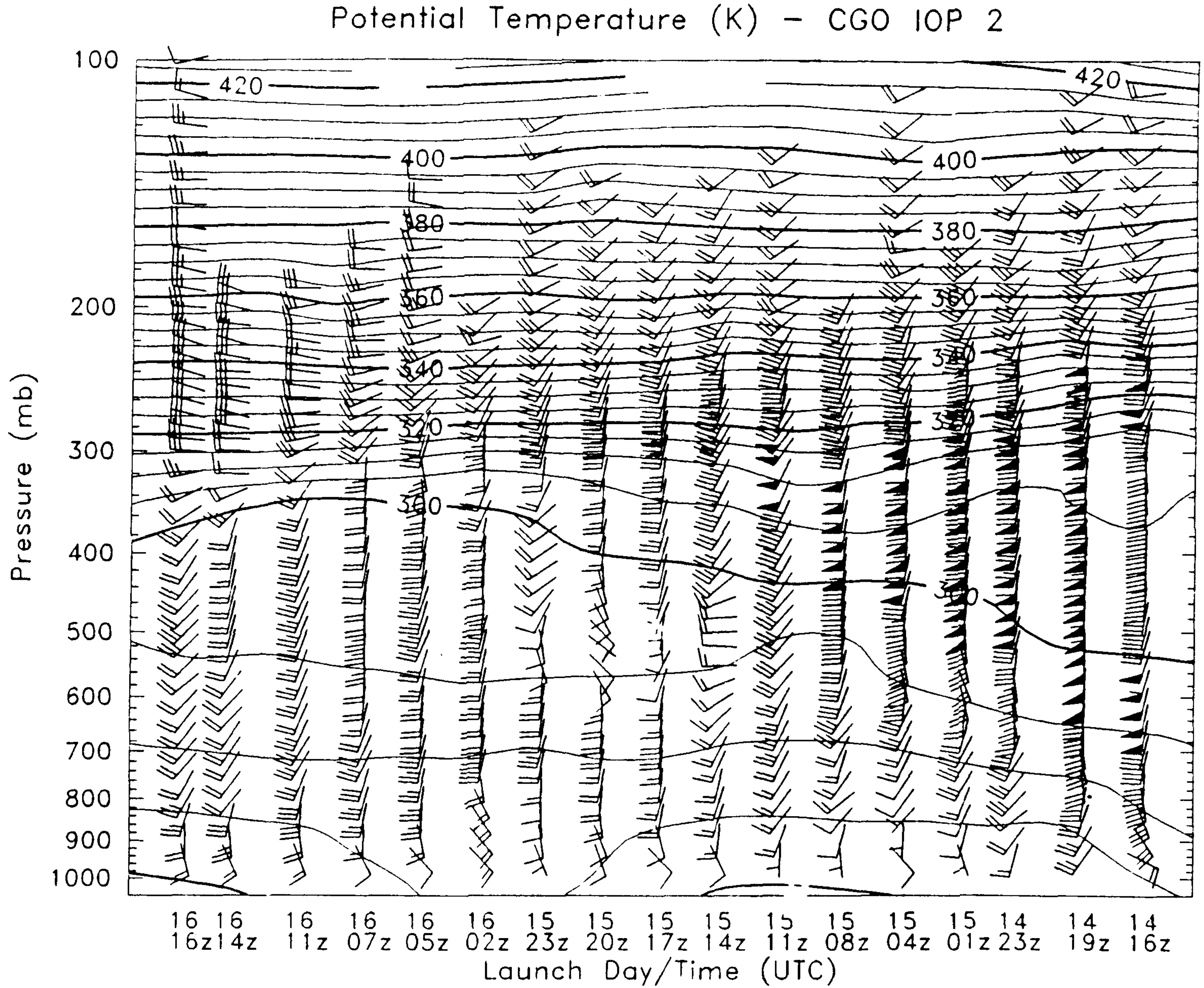

Fig. 7 As in Fig. 3, except for Cottage Grove (CGO).

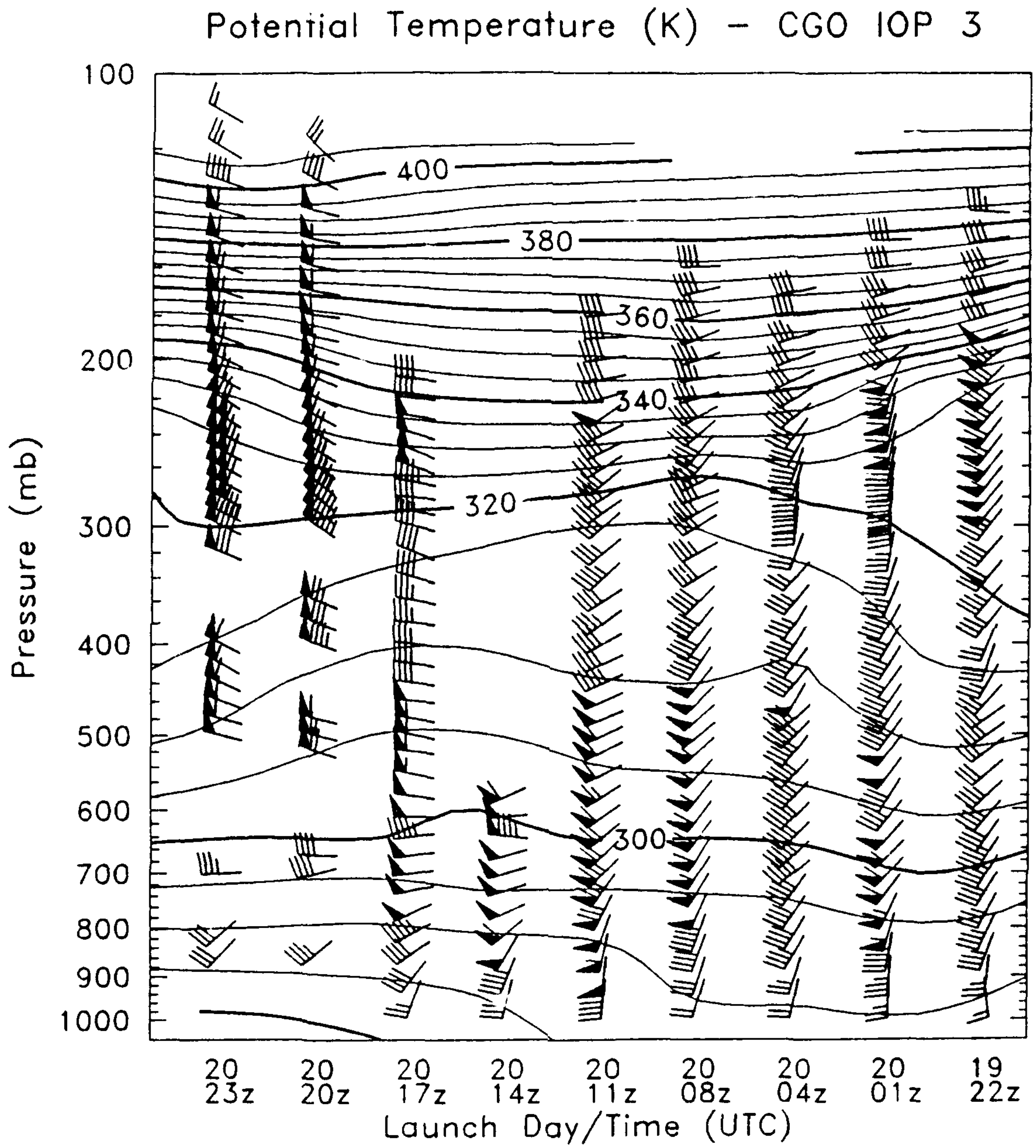

Fig. 7 As in Fig. 3, except for Cottage Grove (CGO).

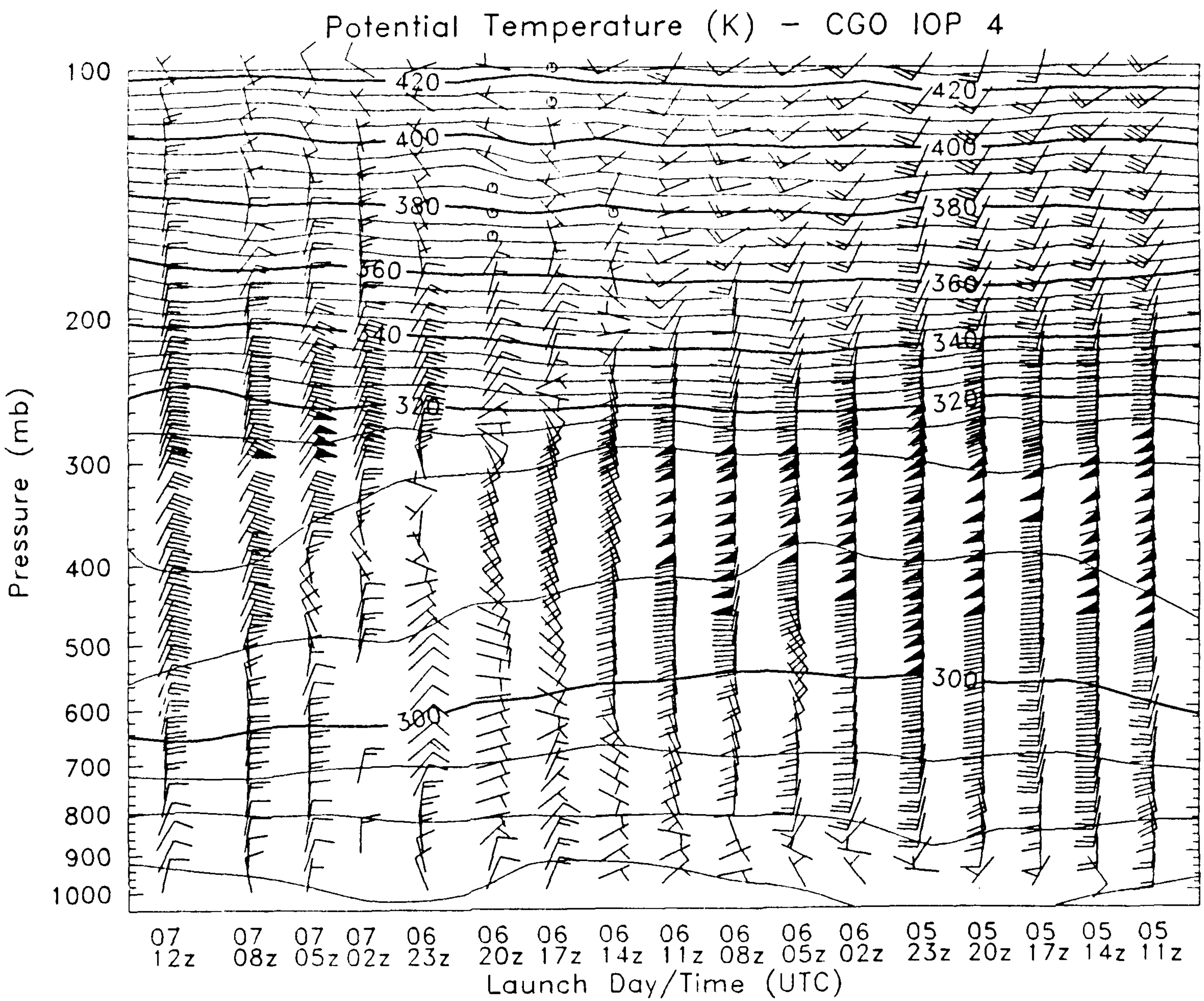

Fig. 7 As in Fig. 3, except for Cottage Grove (CGO).

f. Medford, OR (MFR)

Soundings from the regular NWS rawinsonde site at Medford were processed by NCAR. Table 9 is a list of launch times, minimum pressure and maximum altitudes reached, and special notes related to each launch. Wind vectors and contours of potential temperature for each Picket Fence IOP are given in Fig. 9.

Table 9 Summary of rawinsonde launches from Medford (MFR)

Date	Time	Min. Press	Max. Alt.	Notes
02/13	0500	55.4	19813	
02/13	0802	86.2	16964	
02/13	1109	190.5	11841	
02/13	1403	60.1	19254	
02/13	1701	398.8	7049	Weak signal, Bad Winds.
02/14	1707	31.8	23332	
02/14	2000	42.8	21468	
02/14	2300	8.5	31902	
02/15	0159	152.2	13264	
02/15	0500	92.5	16469	
02/15	0803	84.5	17051	
02/15	1101	123.2	14630	Data missing from NCAR.
02/15	1401	81.4	17309	
02/15	1702	190.6	11767	Weak signal.
02/15	2001	35.1	22792	
02/15	2301	9.5	31190	
02/16	0200	65.5	18674	
02/16	0500	106.9	15558	
02/16	0805	117.7	14940	
02/16	1100	105.4	15648	
02/16	1400	165.3	12731	
02/16	1700	63.3	18995	
02/19	2302	6.5	33494	
02/20	0202	27.0	24377	
02/20	0500	48.2	20778	
02/20	0804	115.5	15234	
02/20	1103	67.5	18601	
02/20	1402	221.1	11052	
02/20	1701	25.2	24925	
02/20	2002	35.2	22785	Data only to 330 mb.
02/20	2301	32.8	23214	Data only to 280 mb.
03/05	1103	113.7	15216	
03/05	1402	27.0	24422	
03/05	1702	40.3	21875	
03/05	2002	54.8	19926	
03/05	2304	28.7	24048	
03/06	0202	190.4	11894	
03/06	0502	235.6	10514	
03/06	0801	65.3	18730	
03/06	1105	173.7	12464	
03/06	1400	118.7	14933	
03/06	1701	40.2	21907	
03/06	2000	59.0	19494	
03/06	2302	7.7	32591	
03/07	0201	167.6	12753	
03/07	0503	143.1	13773	
03/07	0801	191.2	11950	
03/07	1104	39.0	22060	

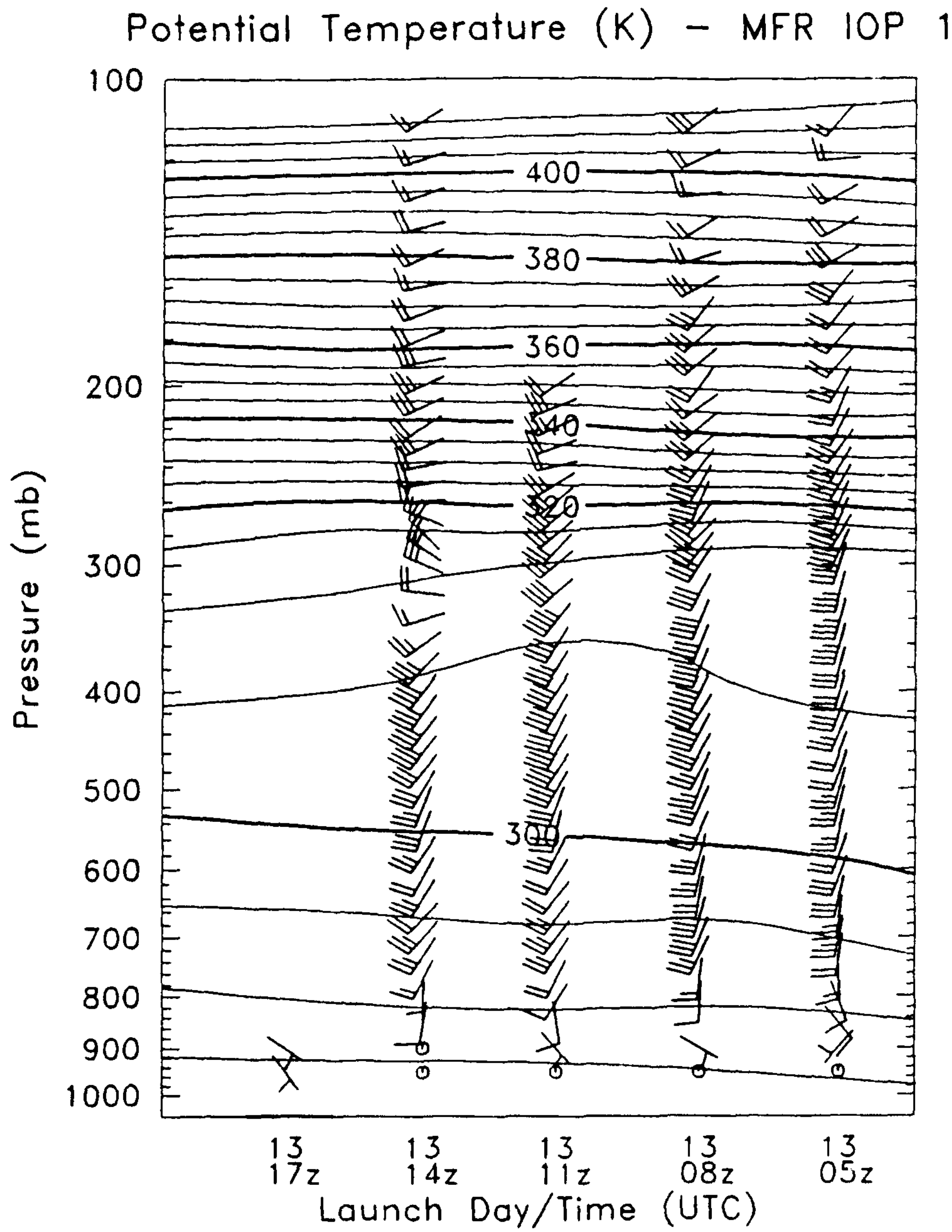

Fig. 8 As in Fig. 3, except for Medford (MFR).

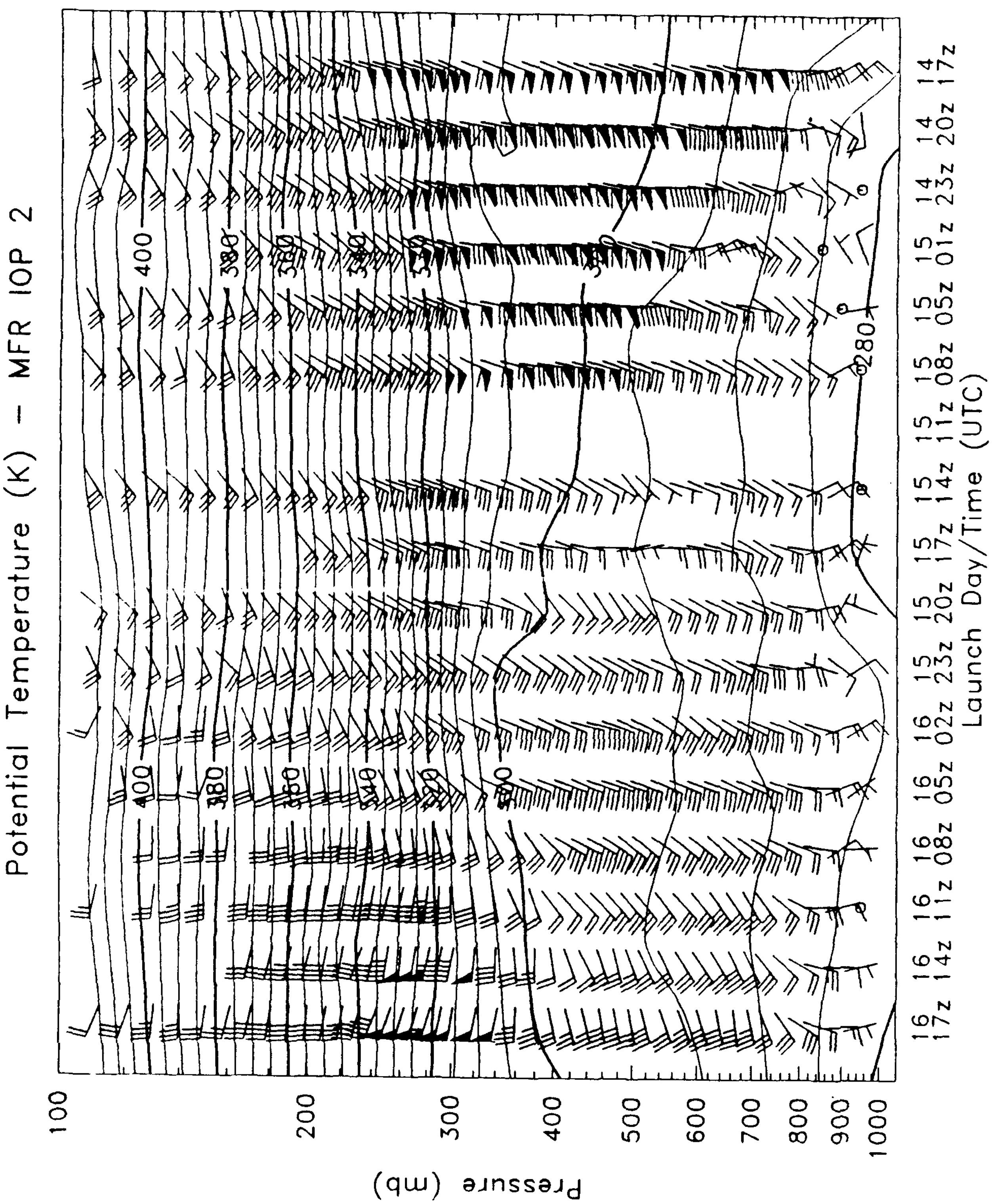

Fig. 8 As in Fig. 3, except for Medford (MFR).

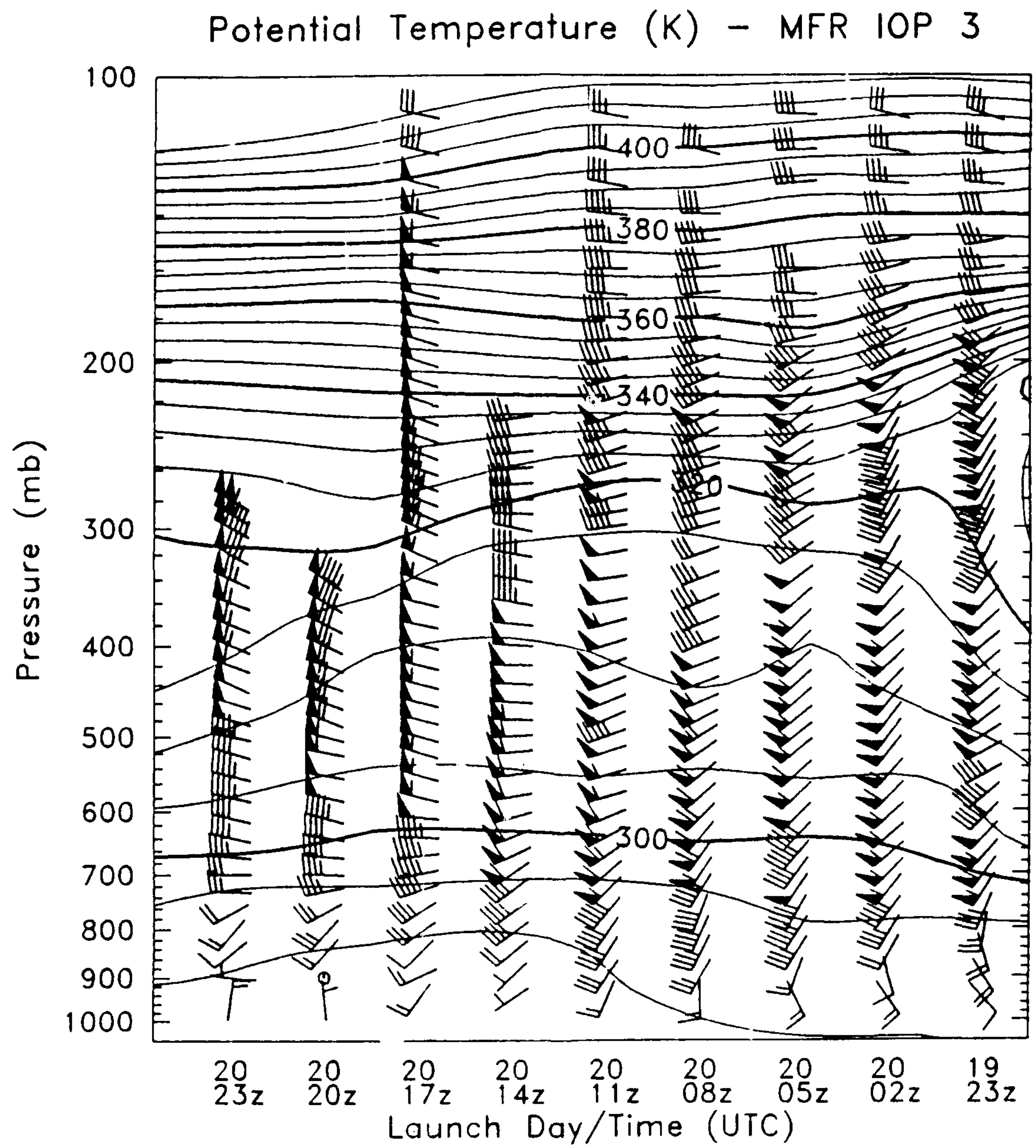

Fig. 8 As in Fig. 3, except for Medford (MFR).

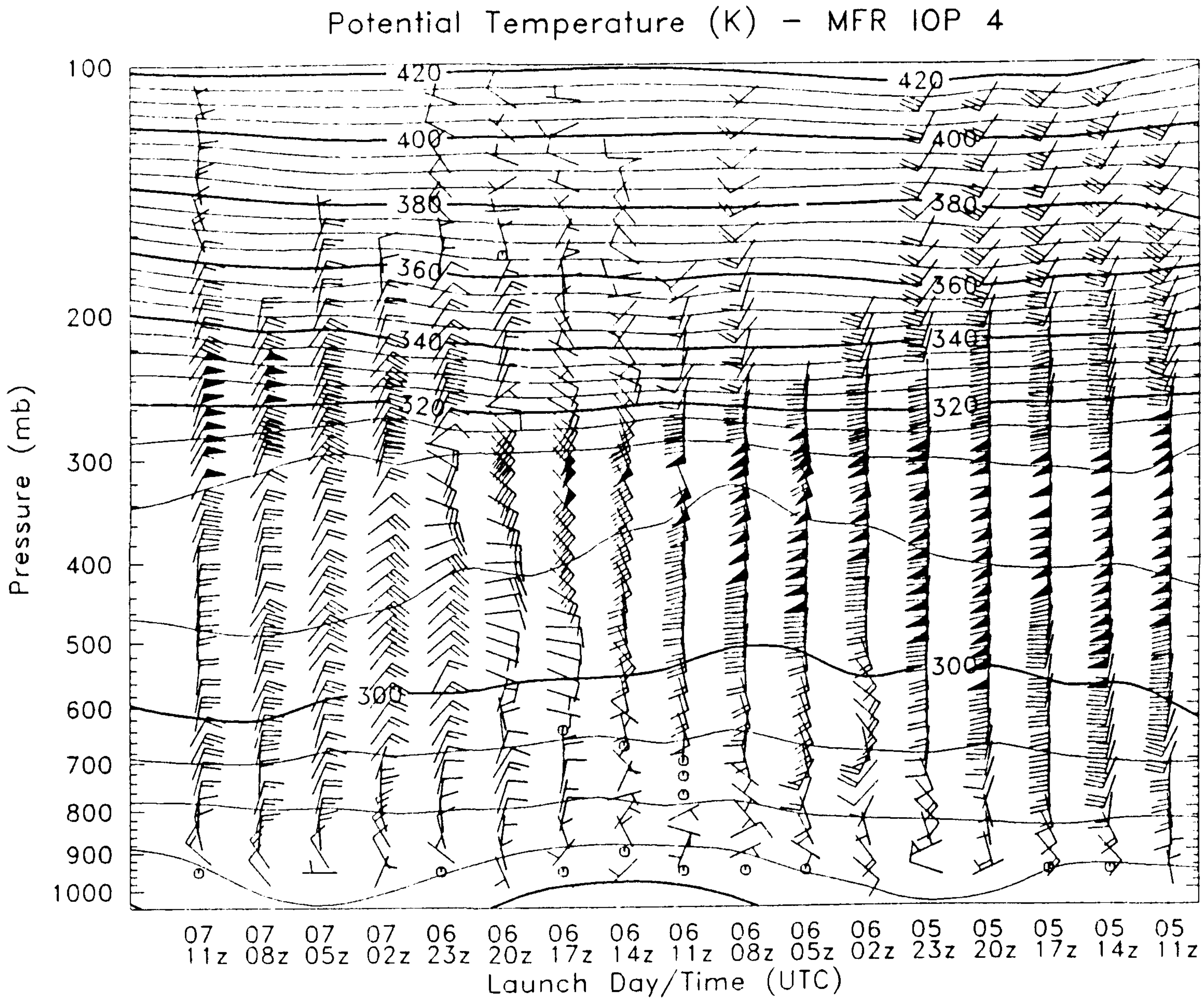

Fig. 8 As in Fig. 3, except for Medford (MFR).

g. **Redding, CA (RDD)**

Launches at the special Picket Fence site in Redding were carried out at the NWS office at Redding Airport. Personnel from the Naval Oceanographic Command Facility (NOCF) San Diego, MET performed the majority of launches, with additional help by a person from NPS. Aside from antenna problems on one launch, there were very few problems. Personnel from the Redding NWS office were intensely interested in our activities. Their support is greatly appreciated.

Table 10 is a list of launch dates and times, minimum pressure level and maximum altitude reached, and notes related to each launch. Wind vectors from each launch overlaid with contours of potential temperature are provided in Fig. 9 for each Picket Fence IOP.

Table 10 Summary of rawinsonde launches from Redding (RDD)

Date	Time	Min. Press	Max. Alt.	Notes
02/13	0605	202.3	11531	
02/13	0802	245.9	10247	
02/13	1200	-----	-----	No launch recorded.
02/13	1411	803.0	1864	Balloon iced, no relaunch
02/13	1710	331.5	8344	
02/14	1800	-----	-----	No launch recorded.
02/14	2010	238.8	10397	
02/14	2318	134.6	14149	
02/15	0216	238.3	10415	
02/15	0526	425.7	6568	Premature balloon burst.
02/15	0838	284.2	9253	
02/15	1118	135.8	14079	
02/15	1426	294.5	8983	
02/15	1745	198.3	11578	
02/15	2031	176.0	12368	
02/15	2319	172.2	12511	
02/16	0217	289.7	9097	
02/16	0515	158.3	13076	
02/16	0811	249.6	10086	
02/16	1211	197.3	11651	
02/16	1431	186.3	12028	
02/16	1649	150.8	13422	
02/19	2325	130.1	14555	
02/20	0212	459.5	6275	Premature balloon burst.
02/20	0512	228.0	10966	
02/20	0820	151.1	13603	
02/20	1119	194.0	11979	
02/20	1427	115.5	15335	
02/20	1749	101.1	16172	
02/20	2008	201.8	11807	
02/20	2304	115.9	15365	
03/05	1203	95.8	16378	
03/05	1443	97.5	16230	
03/05	1723	77.0	17801	SIG and MAND levels only.
03/05	2028	91.9	16640	Winds missing 836-681 mb.
03/05	2327	78.0	17706	
03/06	0230	57.5	19643	
03/06	0527	83.8	17232	No RH<706, winds 706-450.
03/06	0832	90.5	16715	
03/06	1131	152.1	13389	
03/06	1439	121.5	14832	
03/06	1721	141.6	13870	
03/06	2019	51.4	20413	
03/06	2331	155.6	13269	
03/07	0221	215.6	11155	
03/07	0526	93.6	16539	
03/07	0850	225.3	10892	
03/07	1200	-----	-----	No launch recorded.

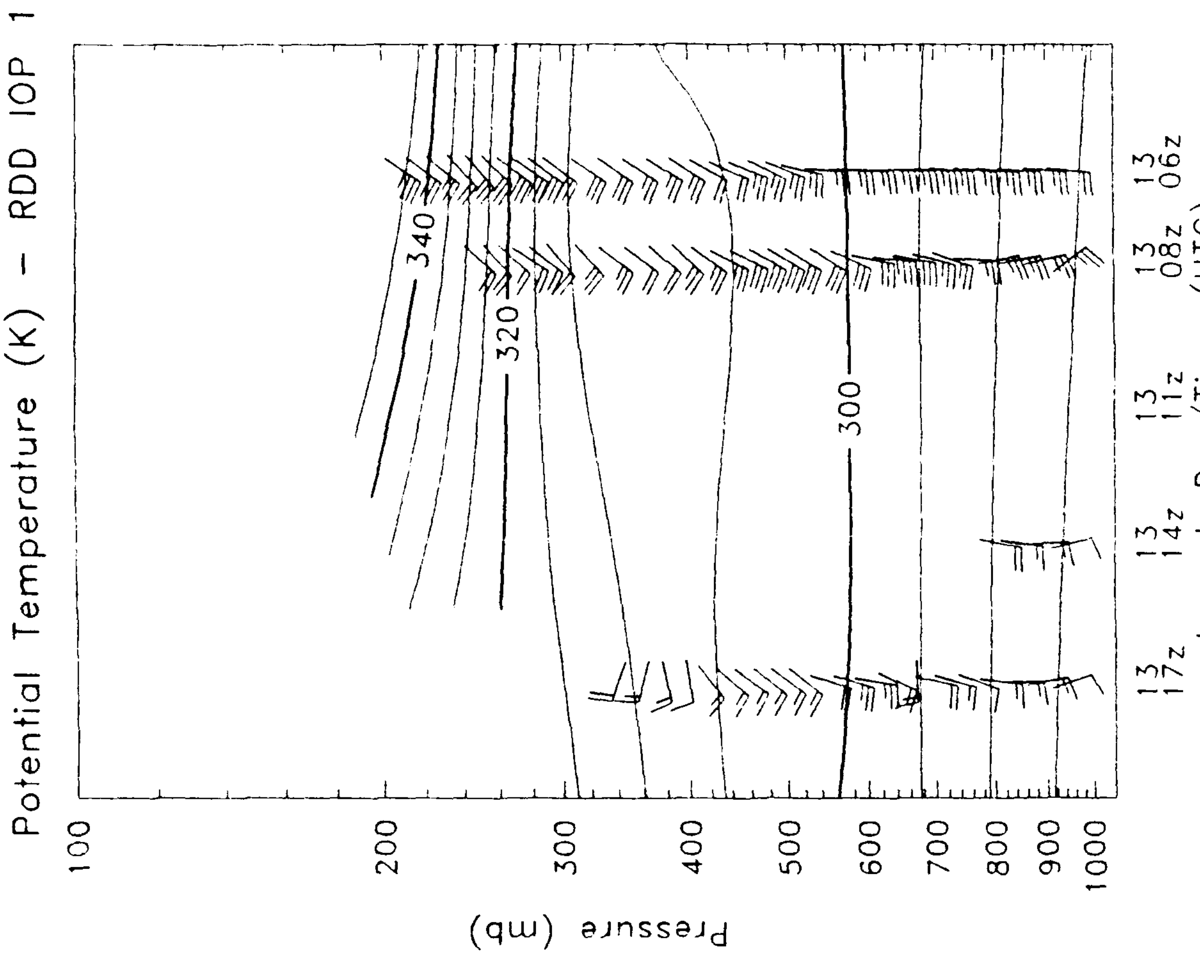

Fig. 9 As in Fig. 3, except for Redding (RDD).

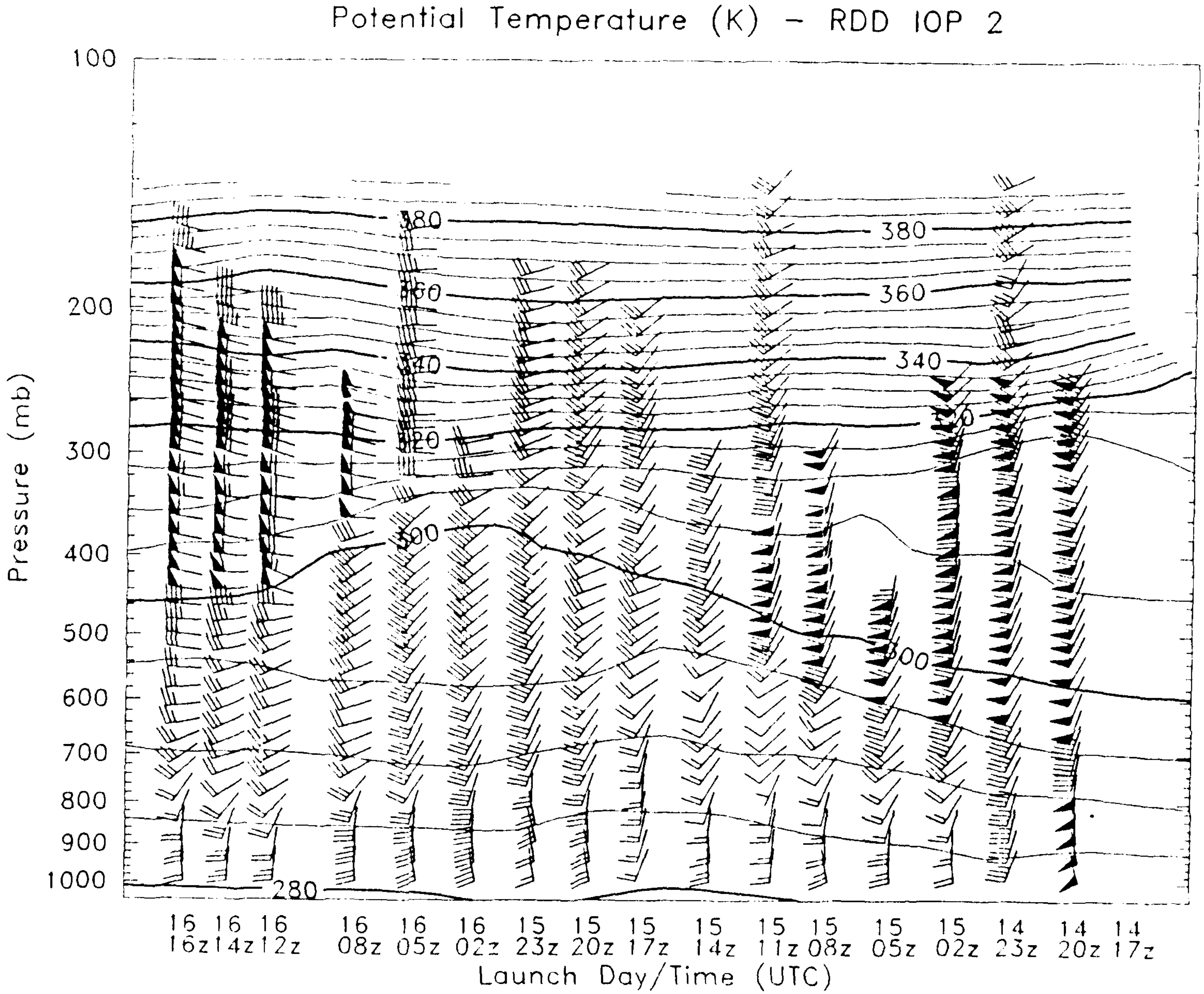

Fig. 9 As in Fig. 3, except for Redding (RDD).

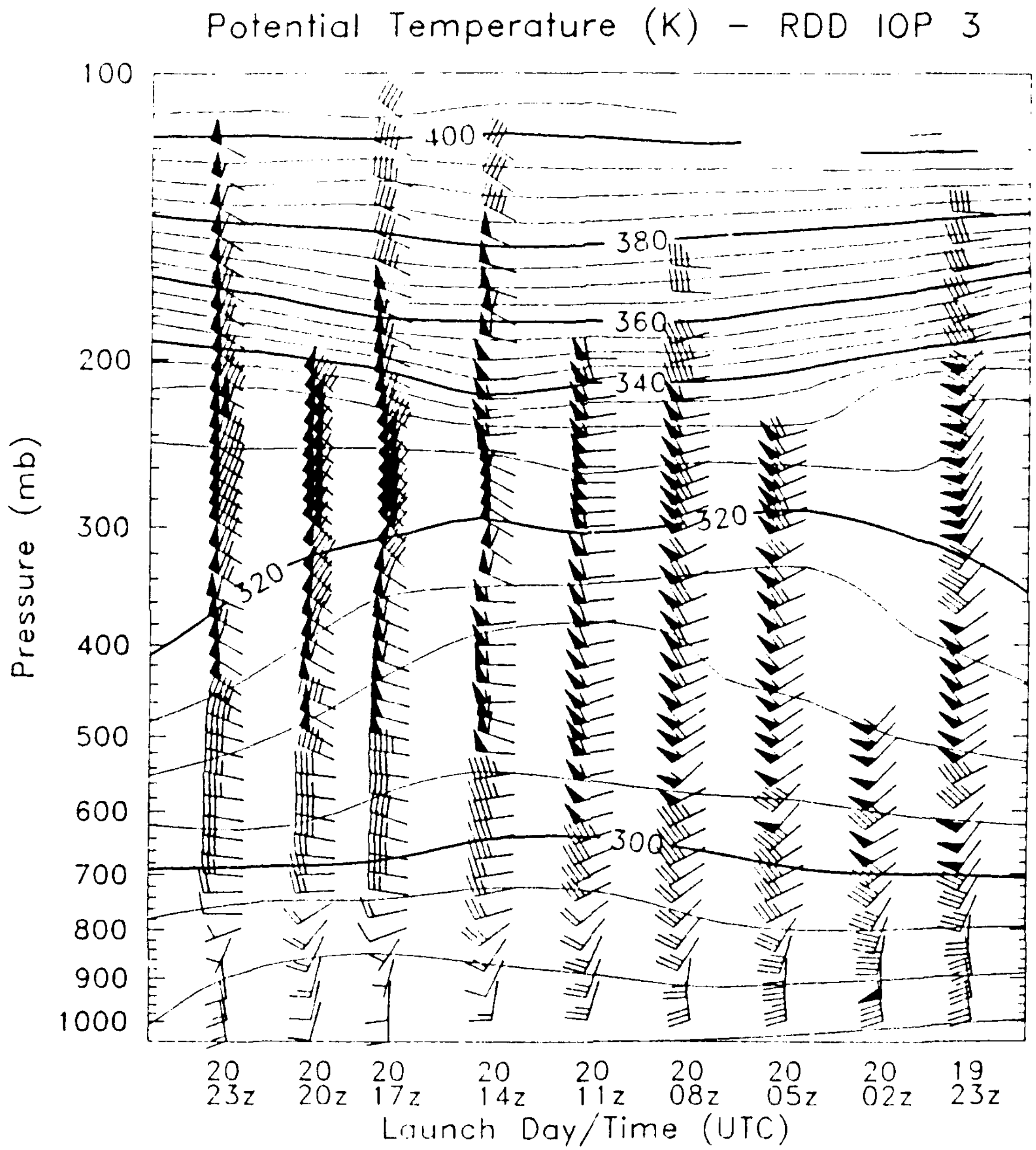

Fig. 9 As in Fig. 3, except for Redding (RDD).

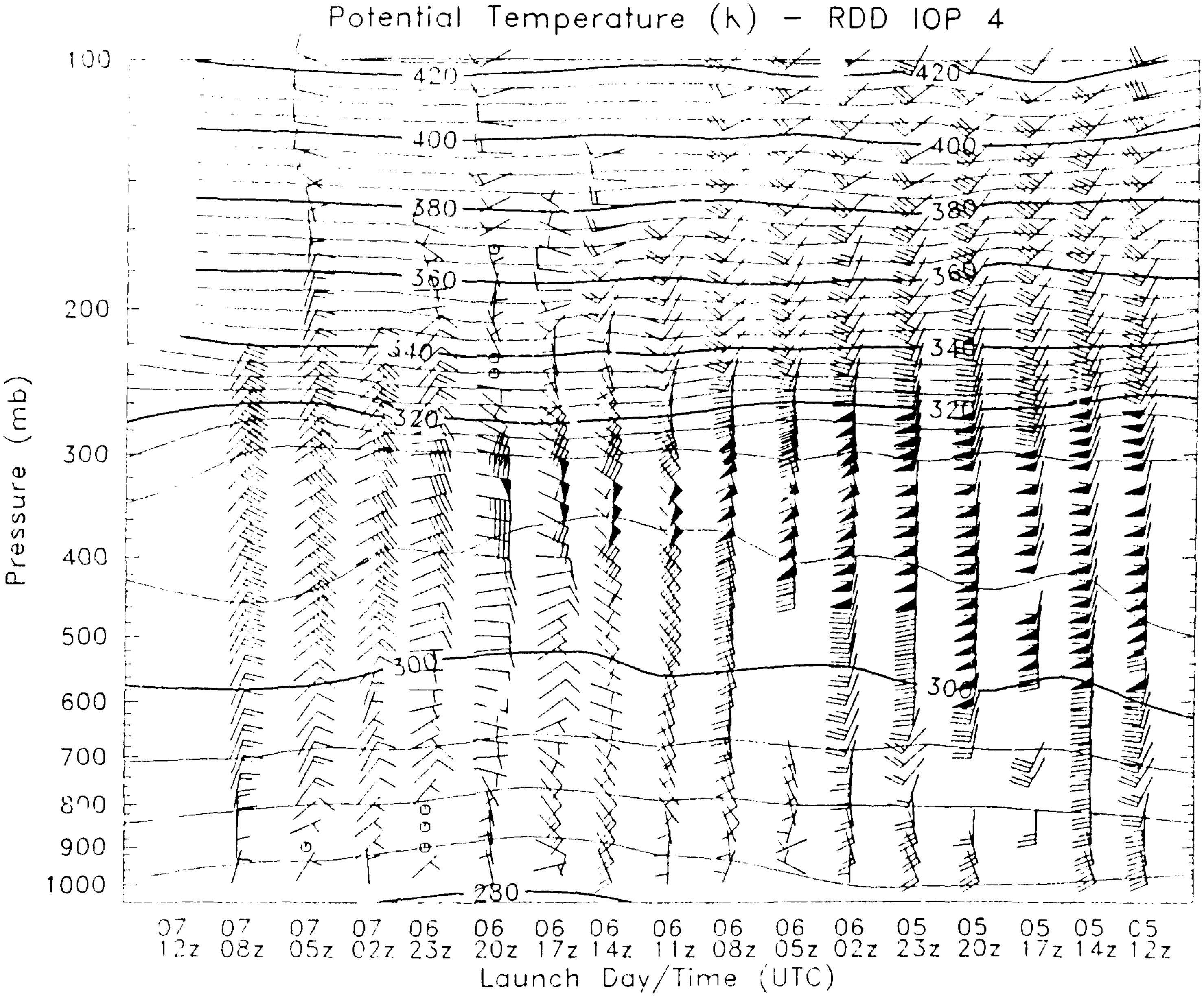

Fig. 9 As in Fig. 3, except for Redding (RDD).

h. **Williams, CA (ILA)**

Launches at the special Picket Fence site at Williams were carried out from a motel room. Management at the motel were very accommodating as they allowed us access to their roof and a storage room. Personnel from the NOCF MET, San Diego, performed the majority of launches. Additional support was provided by personnel from UC Davis and NPS. Aside from a display problem on the PC used to record the data, there were very few problems. The site elevation was erroneously entered as 17 m (instead of 25 m) on some of the launches. For these launches, data at all levels were adjusted to the correct 25 m surface elevation. Surface values were obtained from sonde readouts before each launch.

Table 11 is a list of launch dates and times, minimum pressure level and maximum altitude reached, and notes related to each launch. Wind vectors from each launch overlaid with contours of potential temperature are shown in Fig. 10 for each Picket Fence IOP.

Table 11 Summary of rawinsonde launches from Williams (ILA)

Date	Time	Min. Press	Max. Alt.	Notes
02/13	0518	265.2	9739	Bad winds.
02/13	0756	291.3	9139	
02/13	1100	294.5	9071	
02/13	1407	171.6	12572	
02/13	1700	140.1	13920	
02/14	1655	128.8	14429	
02/14	2012	301.0	8954	
02/14	2256	751.0	2377	Iced. No winds.
02/15	0213	164.3	12834	
02/15	0446	154.3	13246	
02/15	0810	137.5	13979	
02/15	1103	134.1	14147	
02/15	1404	302.2	8807	
02/15	1656	480.1	6300	Weak signal.
02/15	1948	89.5	16765	
02/15	2254	211.6	11171	
02/16	0254	186.3	11984	
02/16	0455	255.3	9945	
02/16	0758	167.6	12705	
02/16	1054	169.1	12648	
02/16	1406	289.7	9196	
02/16	1715	349.3	7972	
02/19	2306	129.6	14563	
02/20	0158	396.5	7338	
02/20	0504	126.1	14754	No winds above 131 mb.
02/20	0756	292.8	9378	
02/20	1050	248.0	10431	
02/20	1401	266.3	9965	
02/20	1655	175.6	12664	
02/20	1947	308.1	9116	
02/20	2245	332.3	8617	
03/05	1118	195.1	11784	
03/05	1424	768.2	2218	Balloon iced.
03/05	1725	59.5	19440	
03/05	2100	-----	-----	Recording equip. failed.
03/05	2324	83.5	17241	
03/06	0231	46.5	20962	
03/06	0532	48.2	20748	
03/06	0825	153.3	13330	SIG and MAND up to 188.
03/06	1124	75.8	17850	
03/06	1439	99.9	16072	
03/06	1729	82.0	17374	
03/06	2020	40.5	21920	
03/06	2315	129.0	14470	No winds 900-655, 622-464
03/07	0247	276.1	9510	
03/07	0526	62.0	19169	
03/07	0824	230.6	10702	
03/07	1117	223.0	10916	

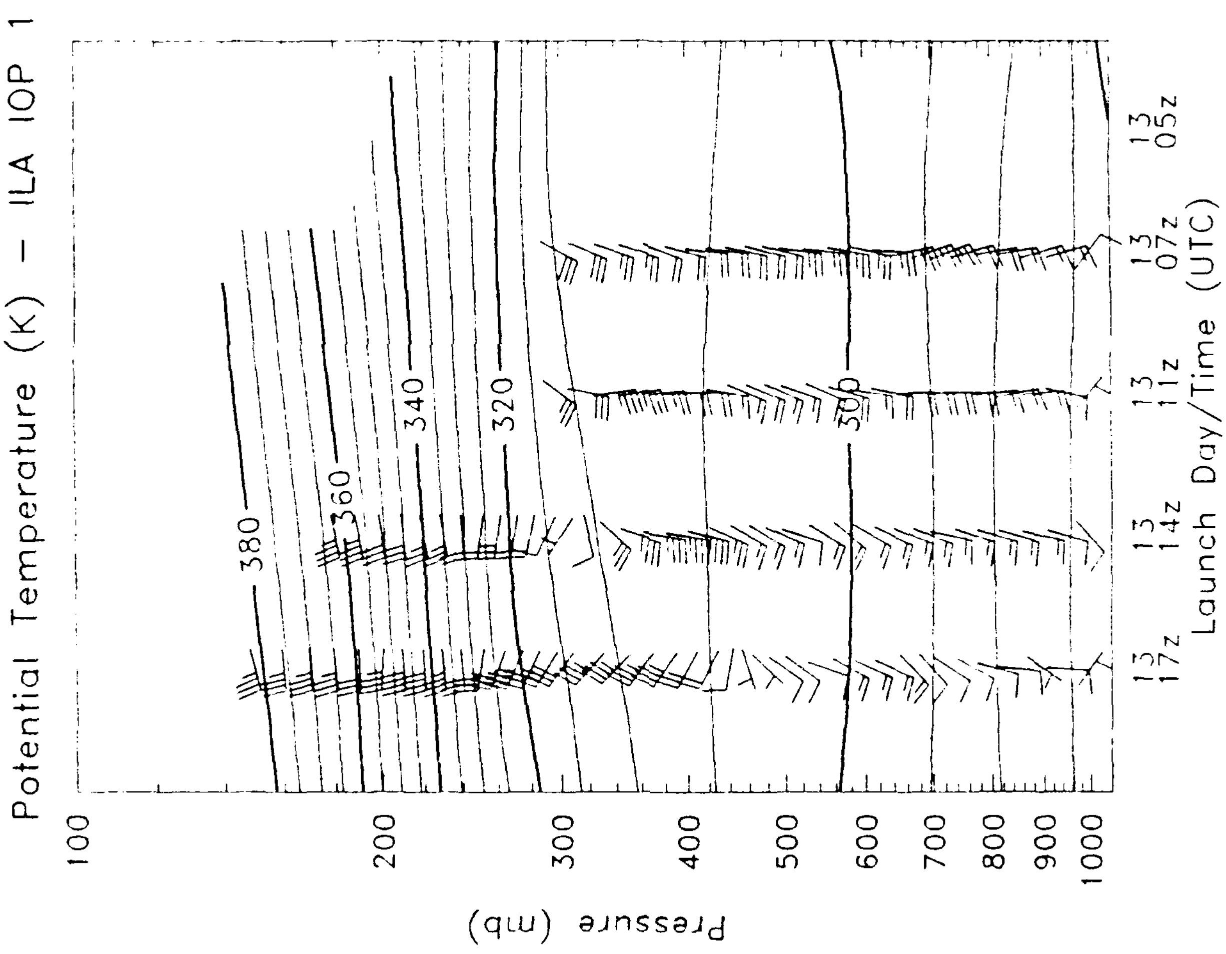

Fig. 10 As in Fig. 3, except for Williams (ILA)

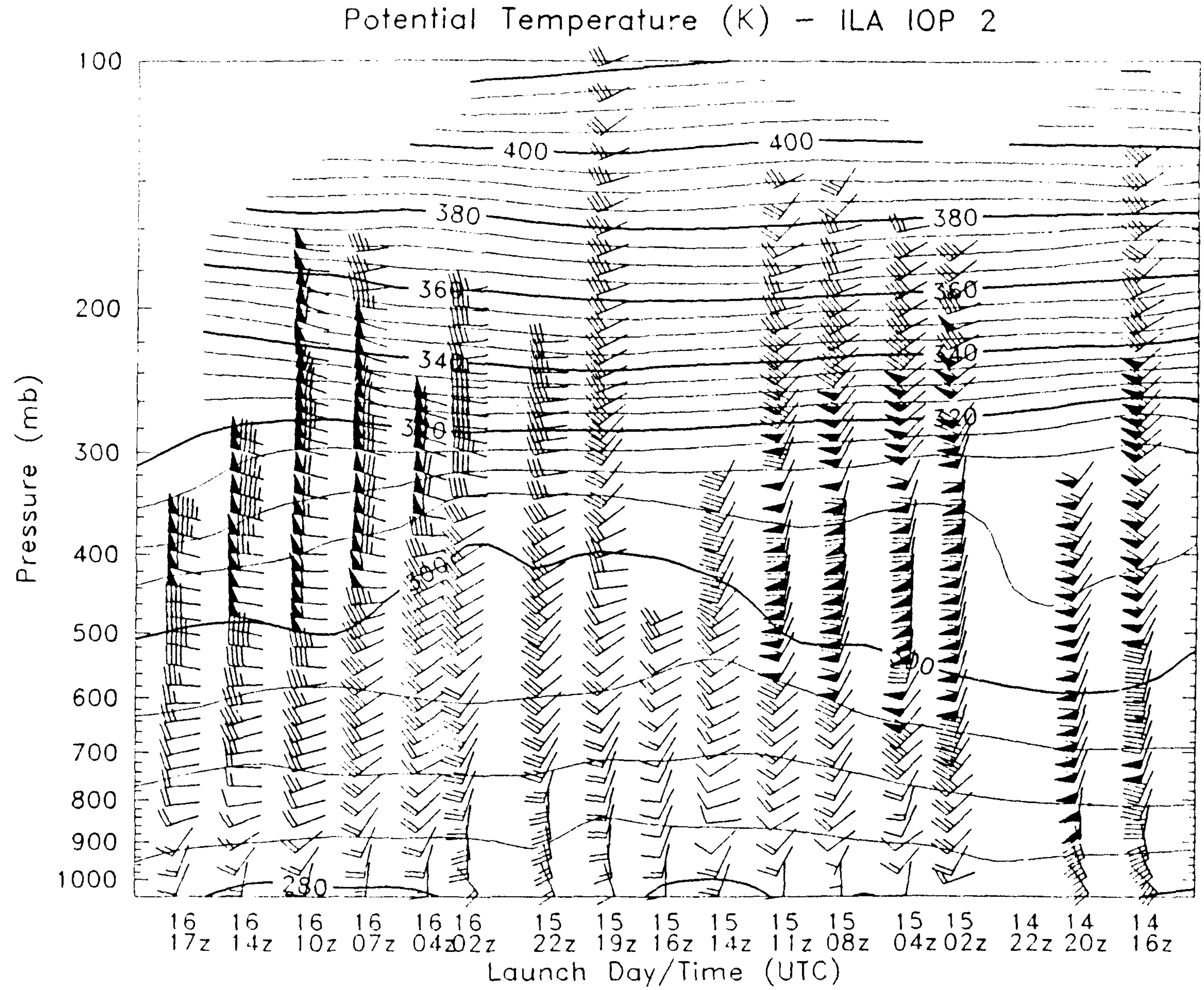

Fig. 10 As in Fig. 3, except for Williams (ILA)

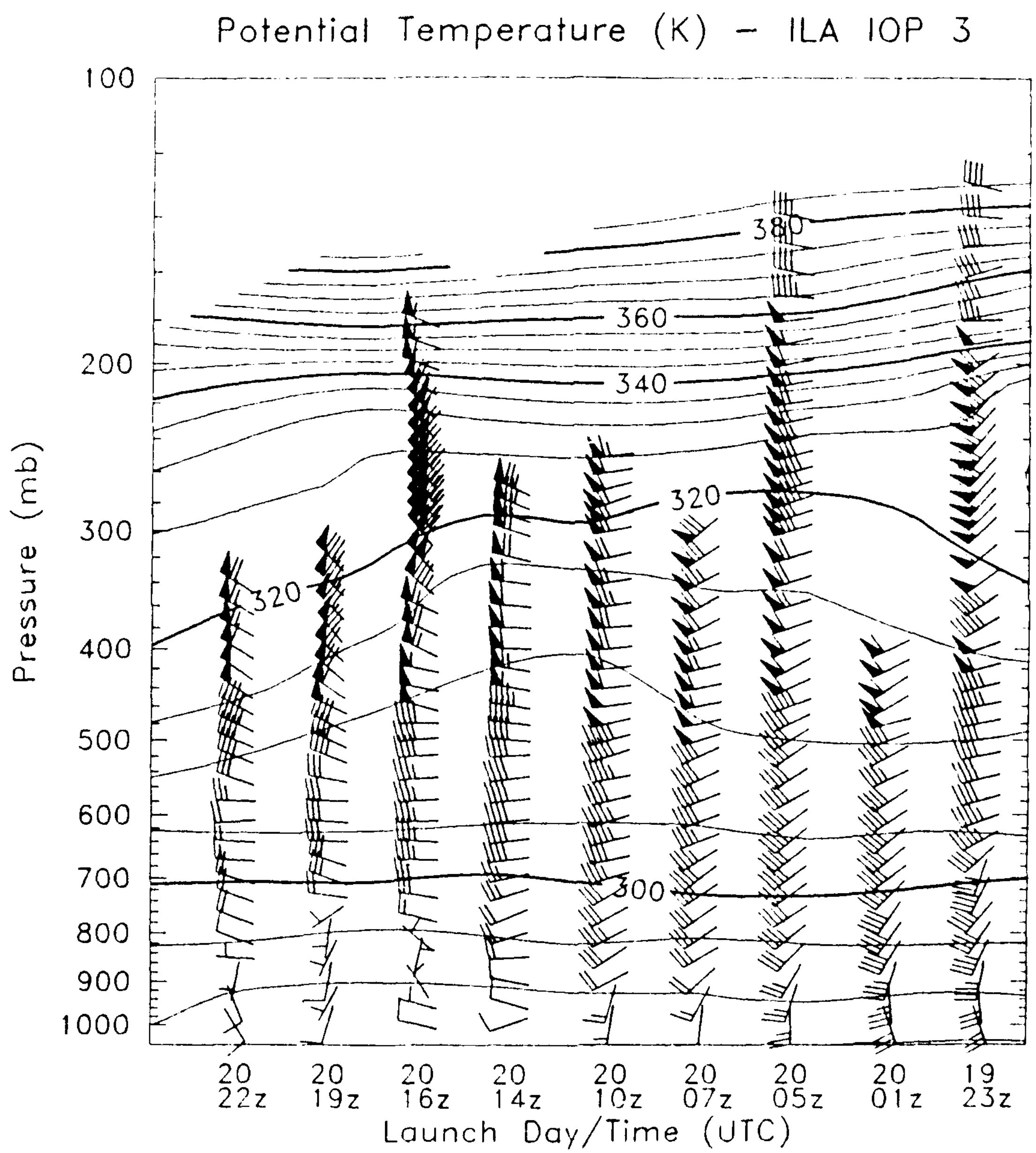

Fig. 10 As in Fig. 3, except for Williams (ILA)

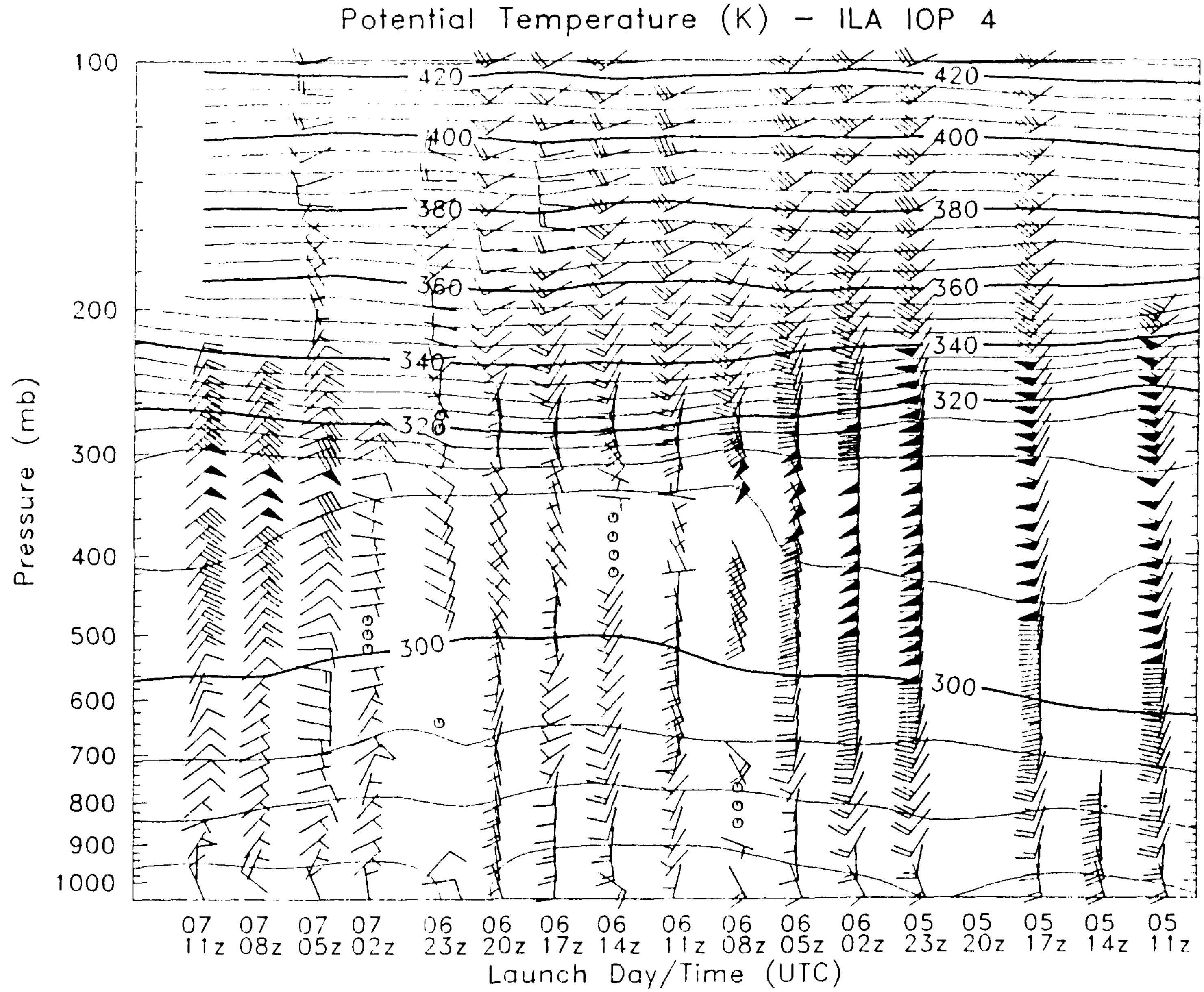

Fig. 10 As in Fig. 3, except for Williams (ILA)

i. **Oakland, CA (OAK)**

Soundings from the regular NWS rawinsonde site at Oakland were processed by NCAR. Table 12 is a list of launch times, maximum altitudes reached and special notes related to each launch. Wind vectors and contours of potential temperature for each Picket Fence IOP are iilustrated in Fig. 11.

Table 12 Summary of rawinsonde launches from Oakland (OAK)

Date	Time	Max. Alt.	Notes (100 mb cutoff used for all special launches.)
02/13	0505	16126	
02/13	0858	16509	Second release, icing.
02/13	1102	31358	
02/13	1401	16299	
02/13	1700	16334	
02/14	1705	31925	
02/14	2001	24358	
02/15	2302	31835	
02/14	0203	16447	
02/15	0500	16407	
02/15	0800	16049	
02/15	1100	28544	
02/15	1401	16086	
02/15	1702	16347	
02/15	2003	16484	
02/15	2300	31202	
02/16	0200	16259	
02/16	0502	16040	
02/16	0801	16455	
02/16	1101	20368	Data only to 320 mb.
02/16	1401	12227	Pressure cell failure.
02/16	1800	-----	Radiosonde failure, no relaunch.
02/19	2305	27085	
02/20	0201	16591	
02/20	0502	16279	
02/20	0800	16472	
02/20	1104	28900	
02/20	1403	16600	
02/20	1700	16346	
02/20	2000	16778	
02/20	2301	23746	
03/05	1103	27606	
03/05	1500	-----	No launch recorded.
03/05	1703	16329	
03/05	2001	16298	
03/05	2301	29429	
03/06	0202	16314	
03/06	0500	16523	
03/06	0802	16398	
03/06	1201	28677	Second release, icing.
03/06	1500	-----	No launch recorded.
03/06	1800	-----	No launch recorded.
03/06	2100	-----	No launch recorded.
03/06	2301	27521	
03/07	0300	-----	No launch recorded.
03/07	0600	-----	No launch recorded.
03/07	0900	-----	No launch recorded.
03/07	1101	31010	

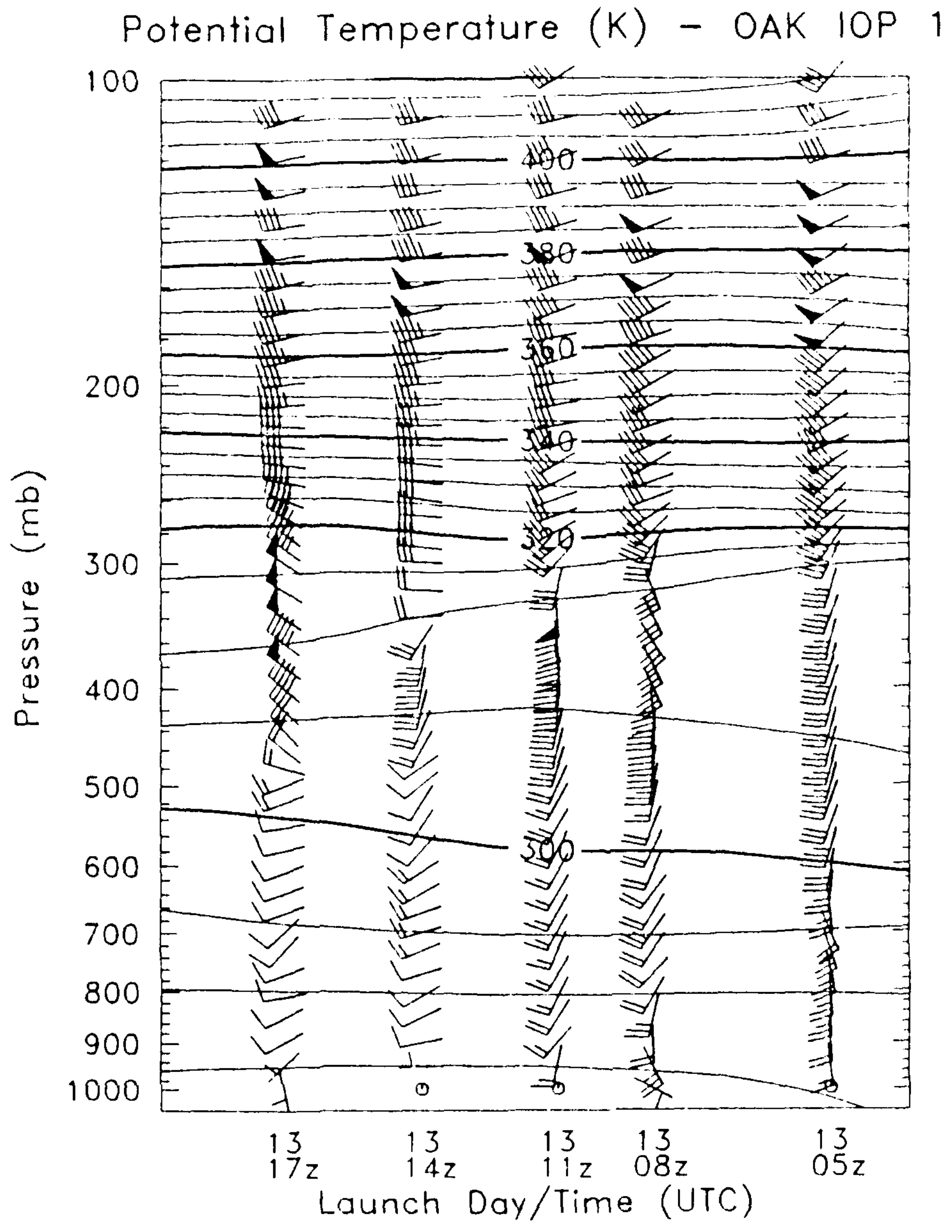

Fig. 11 As in Fig. 3, except for Oakland (OAK).

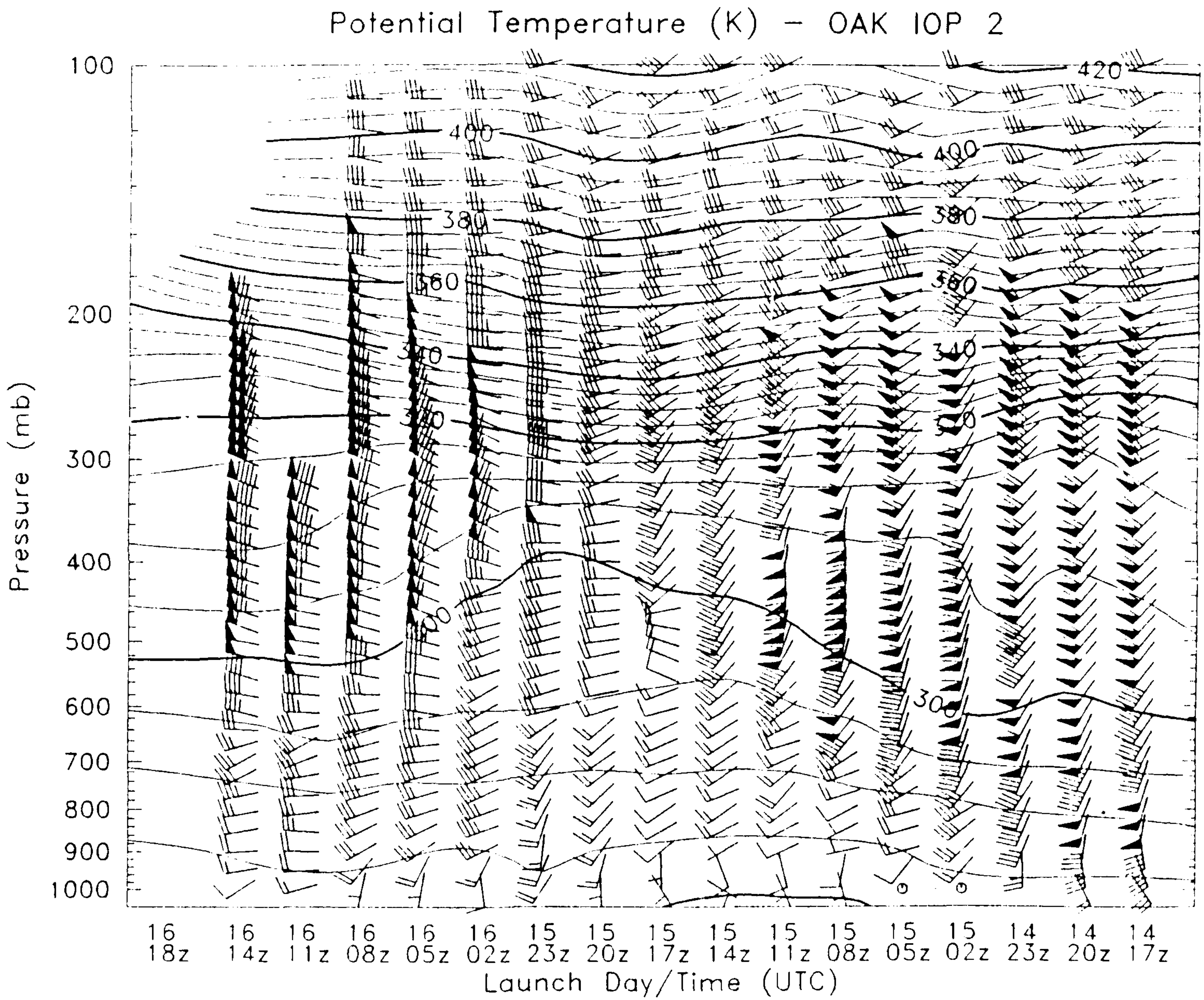

Fig. 11 As in Fig. 3, except for Oakland (OAK).

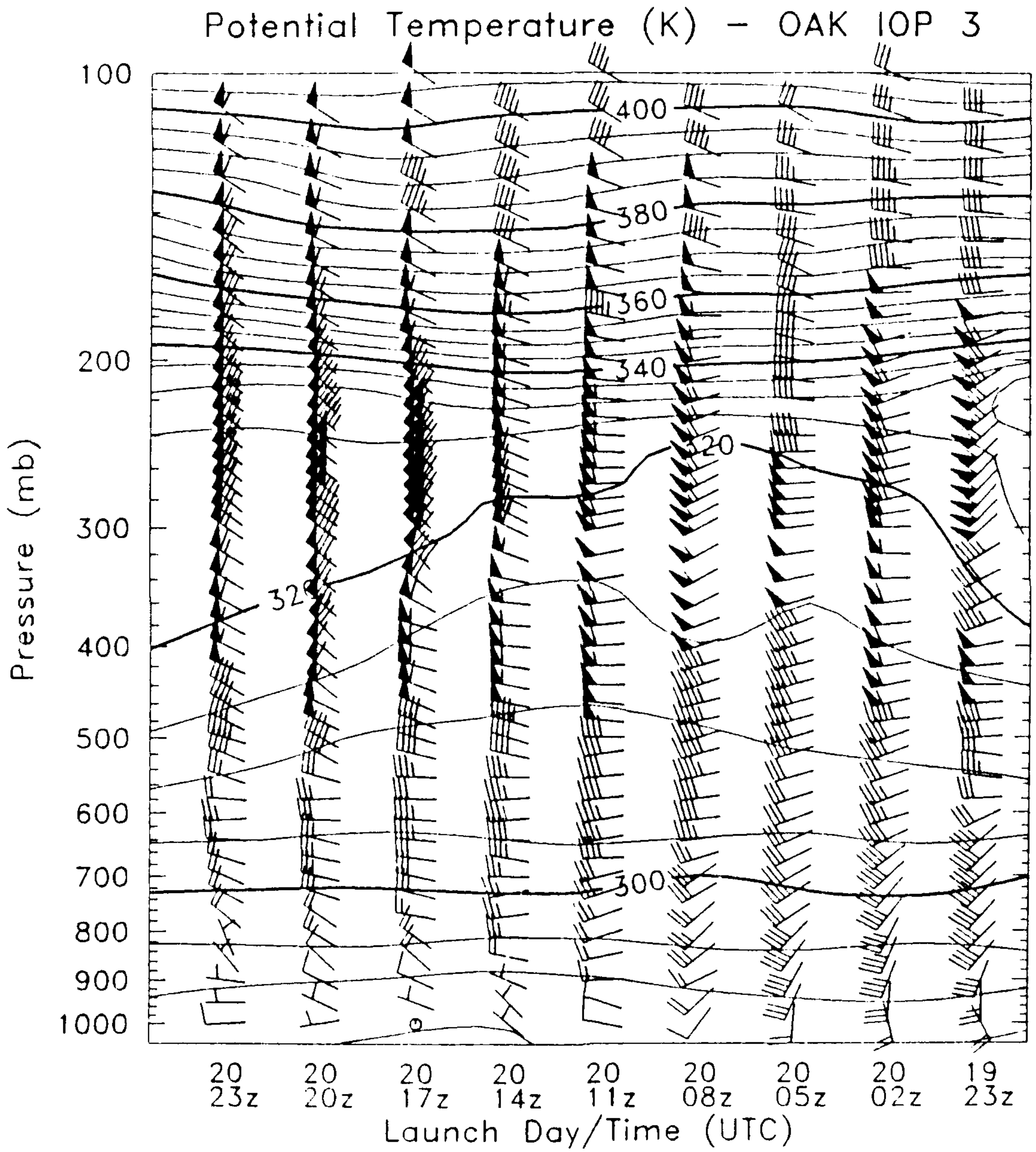

Fig. 11 As in Fig. 3, except for Oakland (OAK).

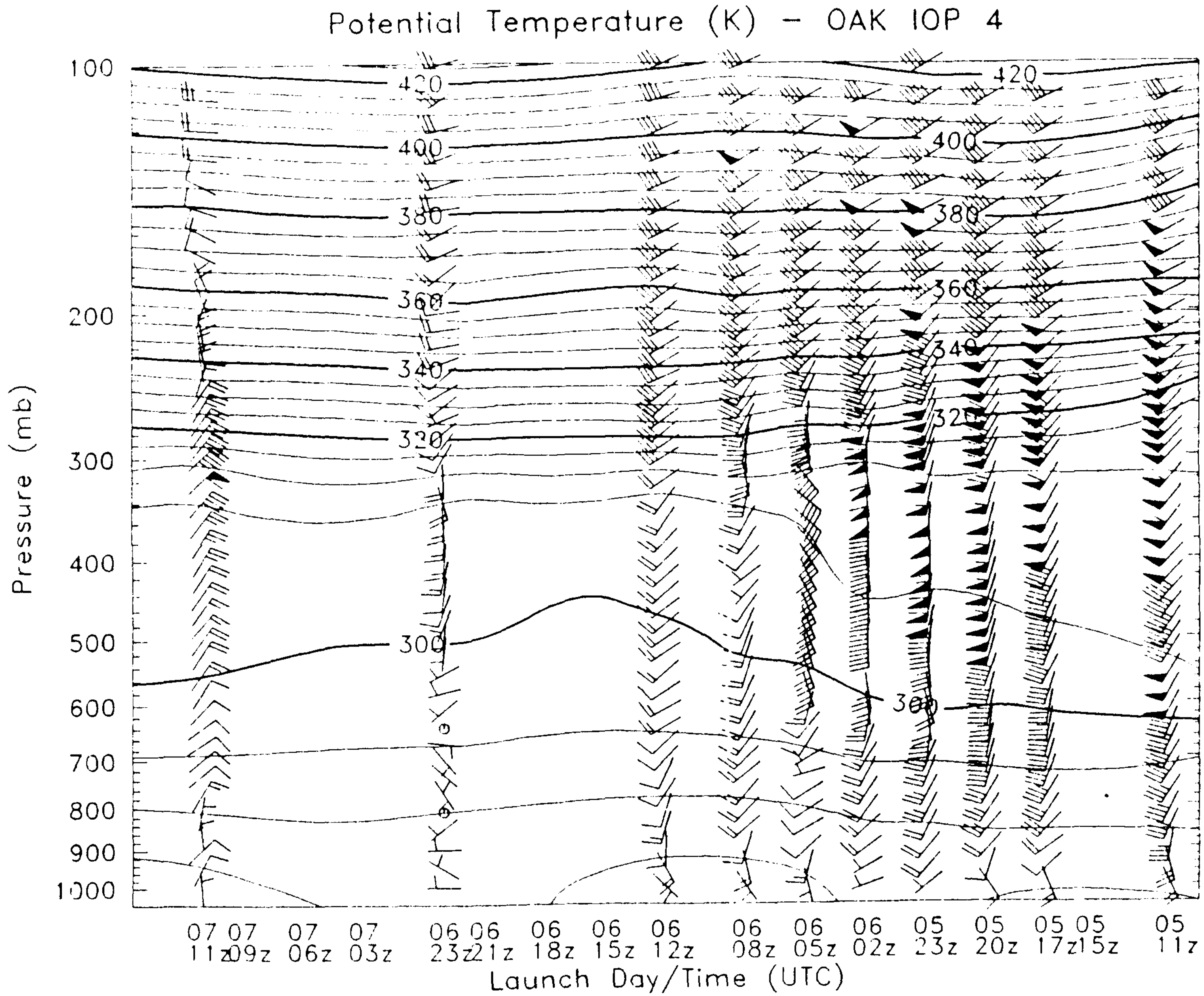

Fig. 11 As in Fig. 3, except for Oakland (OAK).

j. Monterey, CA (NPS)

Launches at the special Picket Fence site in Monterey were made from the campus of the Naval Postgraduate School by NPS personnel. Surface readings were taken from a local meteorological station. Power outages ended two launches prematurely and required manual entry of printer-generated data. During one launch, relative humidity was inadvertently offset by -51%. This was manually corrected and geopotential heights recalculated.

Table 13 is a list of launch dates and times, minimum pressure level and maximum altitude reached, and notes related to each launch. Wind vectors from each launch overlaid with contours of potential temperature are given in Fig. 12 for each Picket Fence IOP.

Table 13 Summary of rawinsonde launches from Monterey (NPS)

Date	Time	Min. Press	Max. Alt.	Notes
02/13	0503	354.8	7863	
02/13	0748	392.7	7173	
02/13	1115	253.5	10066	
02/13	1401	74.6	17927	
02/13	1657	105.6	15773	
02/14	1656	134.3	14195	
02/14	1959	97.5	16275	
02/14	2310	101.5	15998	
02/15	0150	221.1	10967	
02/15	0611	145.6	13655	
02/15	0822	213.8	11155	
02/15	1101	155.3	13236	
02/15	1439	33.2	23078	200 gm balloon.
02/15	1702	161.6	12967	
02/15	1955	165.1	12817	
02/15	2249	148.1	13543	
02/16	0233	218.8	10997	
02/16	0622	212.0	11229	
02/16	0856	171.0	12646	Power outage.
02/16	1048	156.8	13210	
02/16	1500	-----	-----	No launch recorded.
02/16	1800	-----	-----	No launch recorded.
02/19	2254	193.6	12118	
02/20	0206	159.1	13329	
02/20	0503	202.5	11810	
02/20	0804	150.3	13996	
02/20	1102	161.0	13235	
02/20	1400	180.8	12496	
02/20	1701	111.6	15626	
02/20	2001	120.6	15136	
02/20	2302	141.6	14145	
03/05	1200	-----	-----	Recording equip failure.
03/05	1414	54.2	19973	No winds above 86 mb.
03/05	1712	68.1	18582	
03/05	2016	70.5	18385	
03/05	2312	34.9	22828	No winds.
03/06	0223	84.5	17216	No data below 776 mb.
03/06	0530	105.5	15795	
03/06	0819	114.8	15166	No RH above 520 mb.
03/06	1128	43.9	21340	
03/06	1431	101.8	15919	RH bias of -51% fixed.
03/06	1720	49.2	20638	
03/06	2024	32.0	23368	
03/06	2326	38.7	22140	
03/07	0237	205.5	11452	
03/07	0538	187.6	12059	
03/07	0837	96.4	16318	No winds.
03/07	1131	40.4	21867	

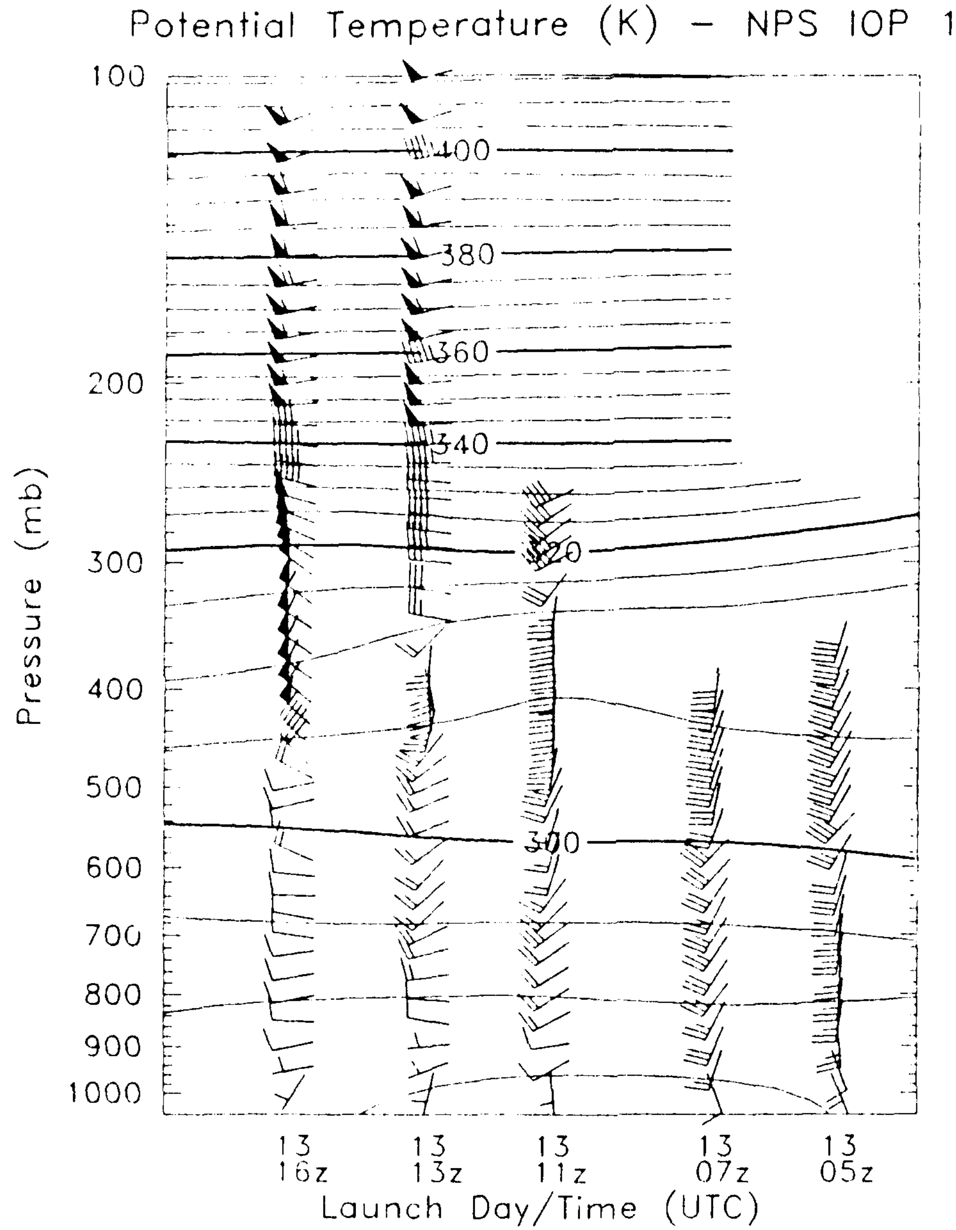

Fig. 12 As in Fig. 3, except for Monterey (NPS).

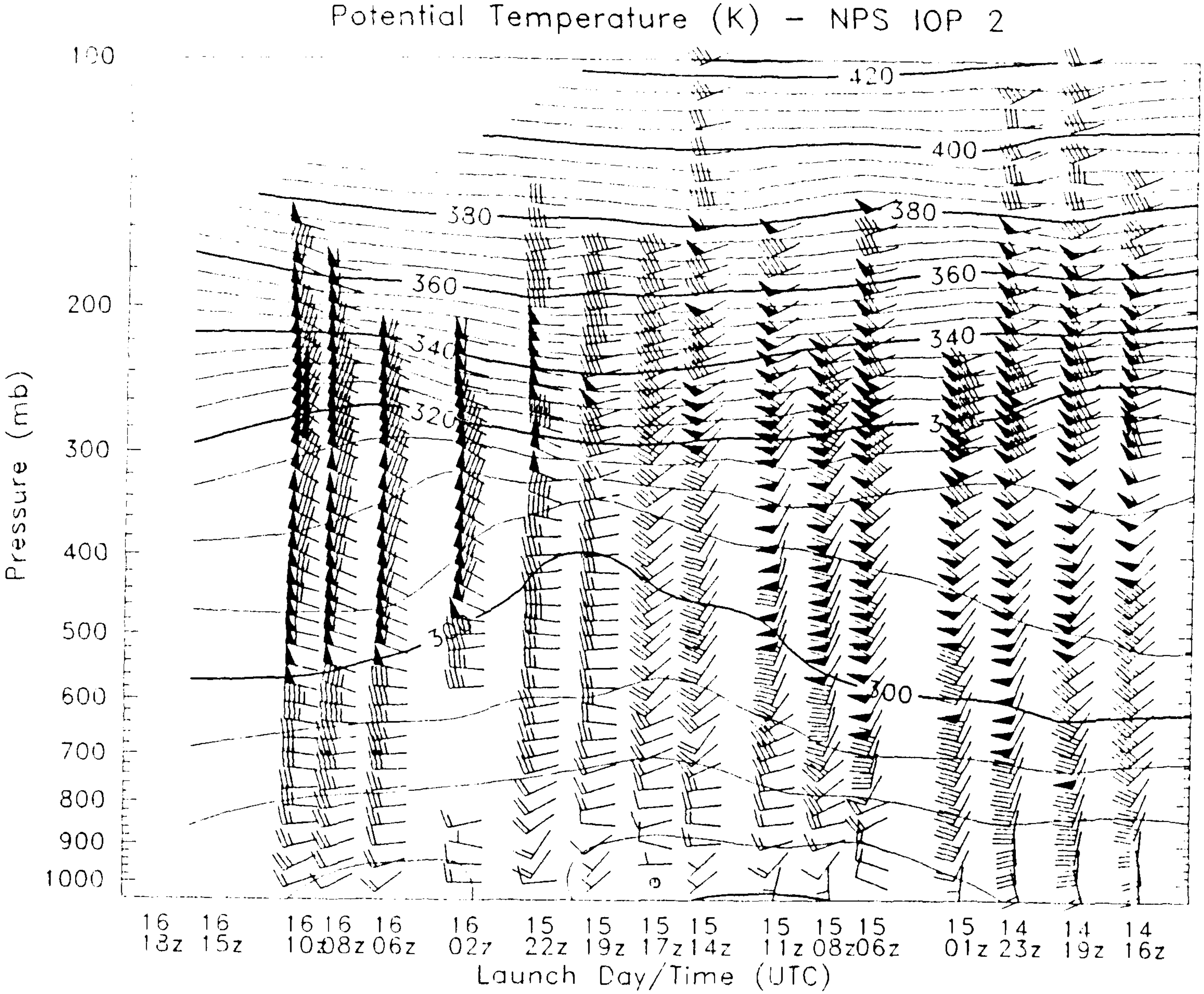

Fig. 12 As in Fig. 3, except for Monterey (NPS).

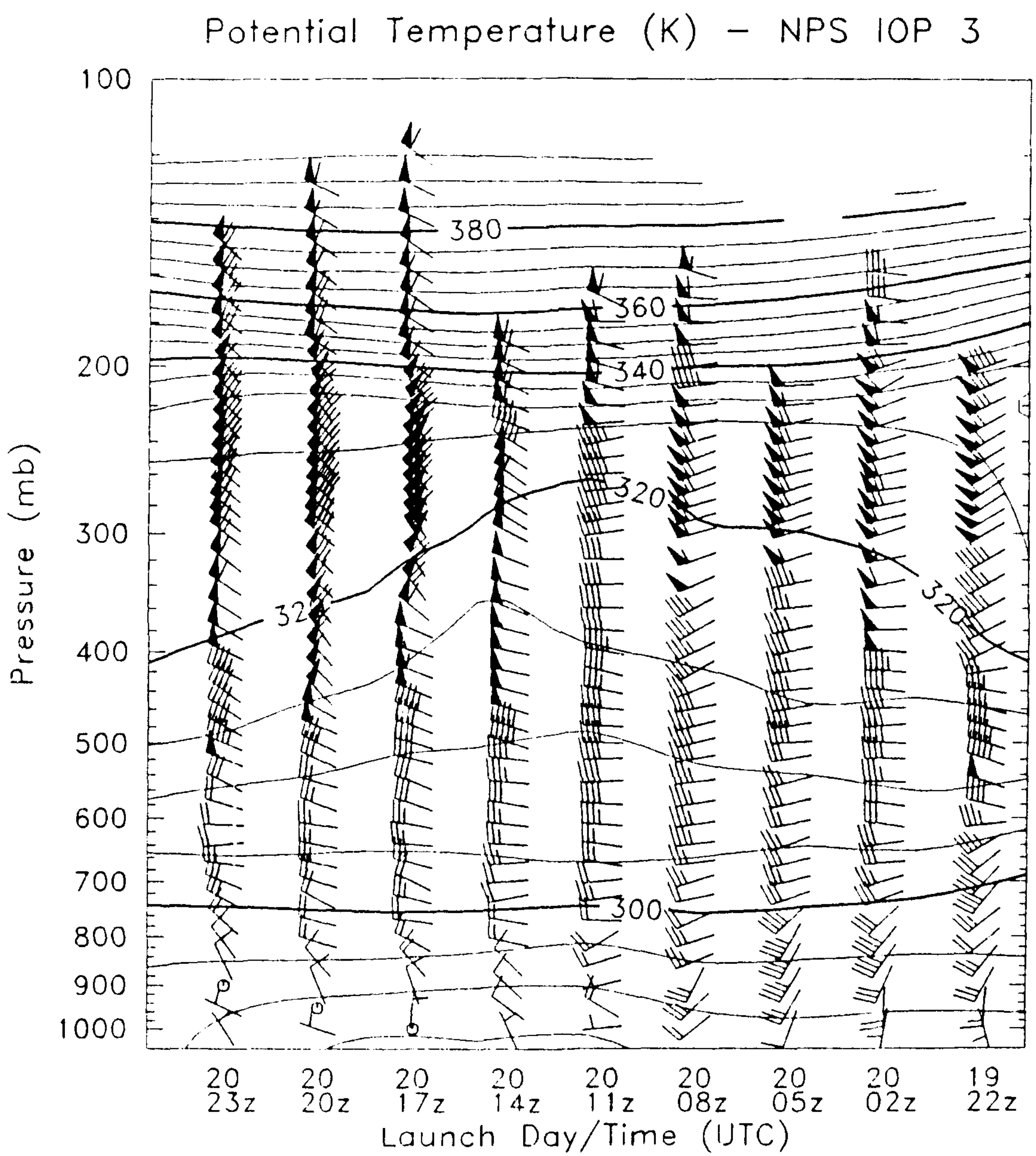

Fig. 12 As in Fig. 3, except for Monterey (NPS).

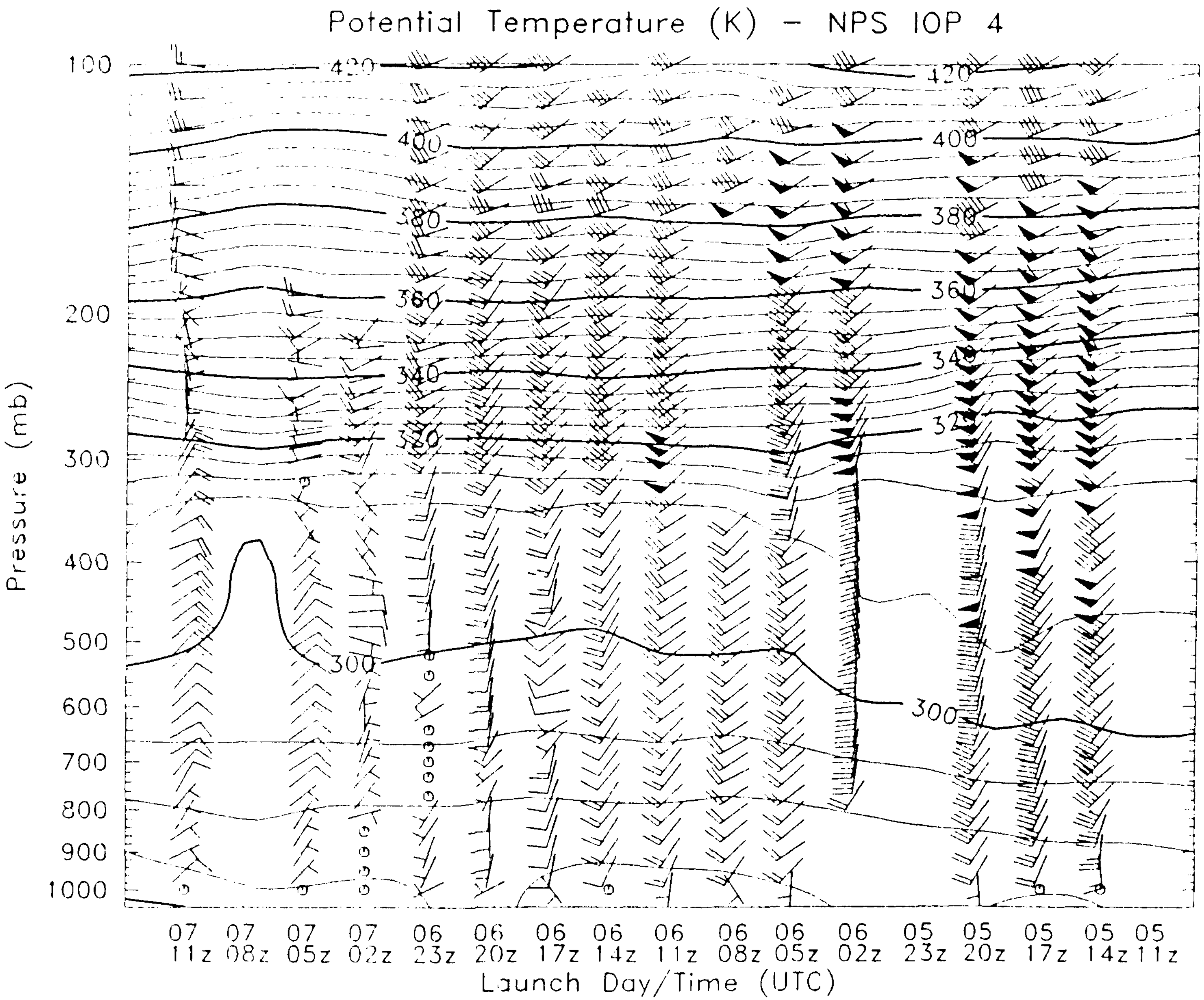

Fig. 12 As in Fig. 3, except for Monterey (NPS).

k. **Paso Robles, CA (PRB)**

Launches at the special Picket Fence site in Paso Robles were carried out at the Paso Robles airport by personnel from NPS and the MET personnel from San Diego. Icing problems aborted four launches. Surface observations were taken from the contract NWS office at PRB. Two launches were corrected for erroneous sonde pressures identified by observing the series of 500 mb geopotential heights. These sonde pressure errors were less than 10 mb. Several launches required restarts was the site was plagued by weak signal problems. For some reason, the MRS did not report humidity after restarting.

Table 14 is a list of launch dates and times, minimum pressure level and maximum altitude reached, and notes related to each launch. Wind vectors from each launch overlaid with contours of potential temperature are presented in Fig. 13 for each Picket Fence IOP.

Table 14 Summary of rawinsonde launches from Paso Robles (PRB)

Date	Time	Min. Press	Max. Alt.	Notes
02/13	0518	716.5	2779	Lost signal.
02/13	0824	793.9	1952	Balloon iced. No winds.
02/13	1054	829.5	1593	Balloon iced.
02/13	1352	175.8	12515	
02/13	1654	146.1	13771	
02/14	1738	127.5	14571	
02/14	1956	171.6	12715	
02/14	2333	144.6	13777	
02/15	0203	151.1	13471	
02/15	0504	191.0	11961	
02/15	0841	209.8	11347	No winds: 924-563 mb.
02/15	1134	677.6	3207	Weak signal.
02/15	1417	134.3	14192	
02/15	1730	108.4	15623	
02/15	1925	207.3	11395	
02/15	2242	499.5	5482	No data 913-716, 680-574.
02/16	0205	308.2	8786	Msg RH <817, all 519-411.
02/16	0544	186.8	12083	No T or RH 265-217 mb.
02/16	0800	201.6	11613	
02/16	1217	137.1	14108	
02/16	1500	-----	-----	No launch recorded.
02/16	1800	-----	-----	No launch recorded.
02/19	2300	237.1	10909	
02/20	0205	196.0	12069	
02/20	0500	131.5	14578	
02/20	0805	200.1	11906	No winds above 205.7 mb.
02/20	1104	150.6	13670	
02/20	1407	119.4	15177	
02/20	1657	91.5	16841	No winds above 94.9 mb.
02/20	2003	235.3	10981	No winds above 241.1 mb.
02/20	2252	126.5	14874	
03/05	1129	919.5	817	Balloon iced. No winds.
03/05	1404	113.6	15318	
03/05	1707	127.1	14652	
03/05	2003	151.5	13516	
03/05	2259	71.0	18340	
03/06	0203	810.5	1818	Balloon iced/floating.
03/06	0500	161.6	13088	
03/06	0803	37.4	22212	
03/06	1101	709.2	2871	Weak signal.
03/06	1354	115.0	15254	
03/06	1706	38.5	22212	
03/06	2005	145.8	13740	
03/06	2317	94.9	16503	
03/07	0205	83.5	17307	
03/07	0506	69.0	18489	
03/07	0801	55.7	19867	
03/07	1058	145.8	13704	

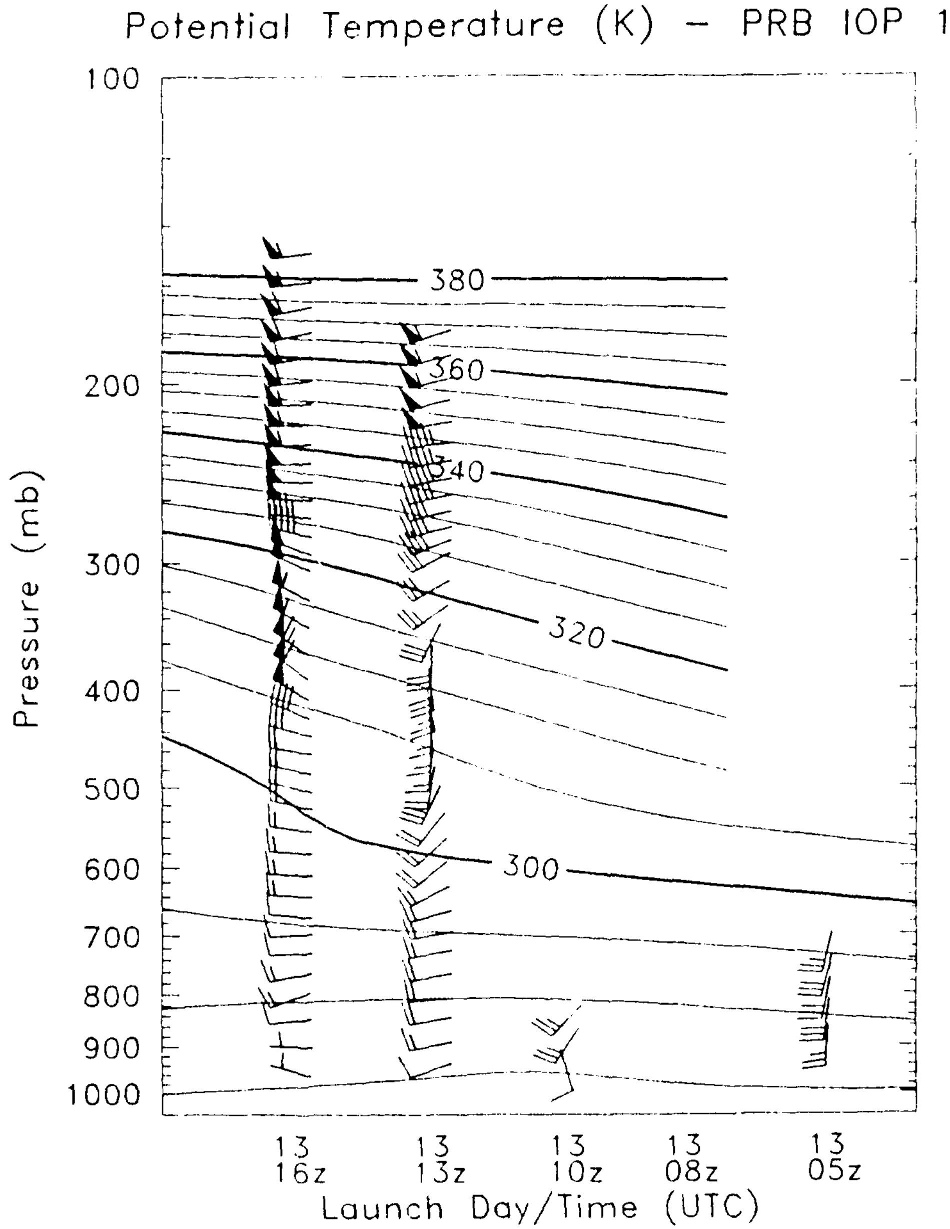

Fig. 13 As in Fig. 3, except for Paso Robles (PRB)

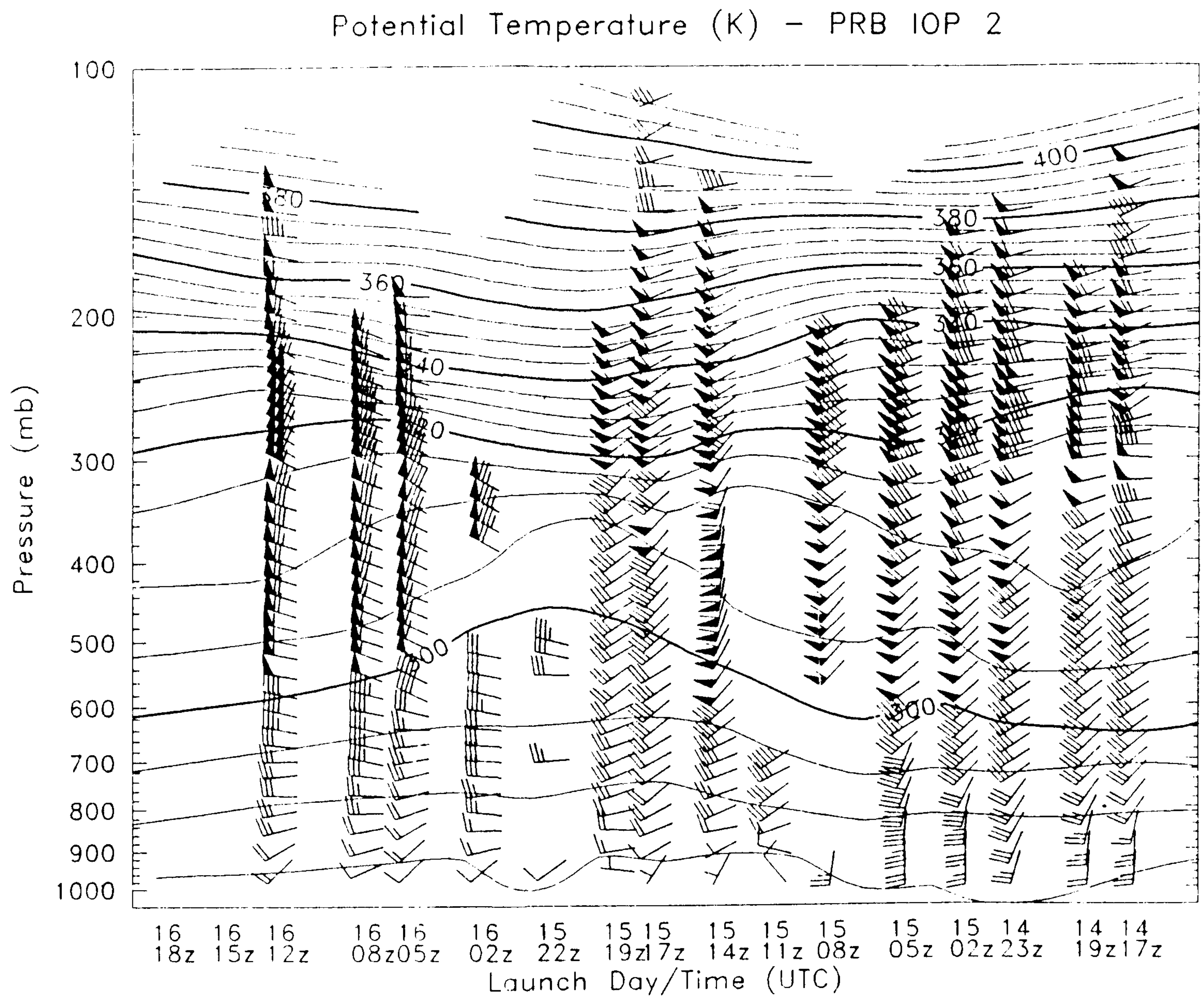

Fig. 13 As in Fig. 3, except for Paso Robles (PRB)

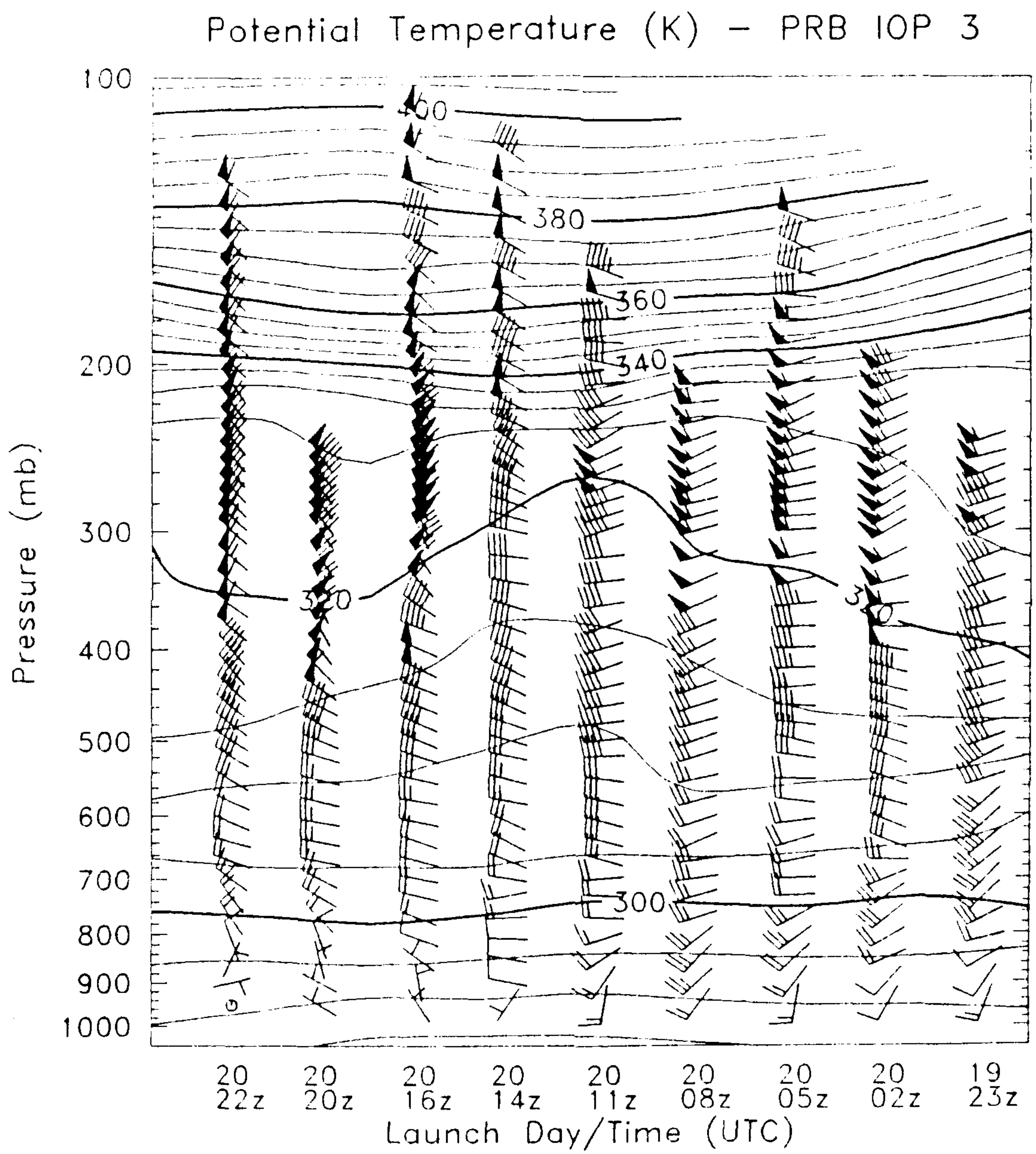

Fig. 13 As in Fig. 3, except for Paso Robles (PRB)

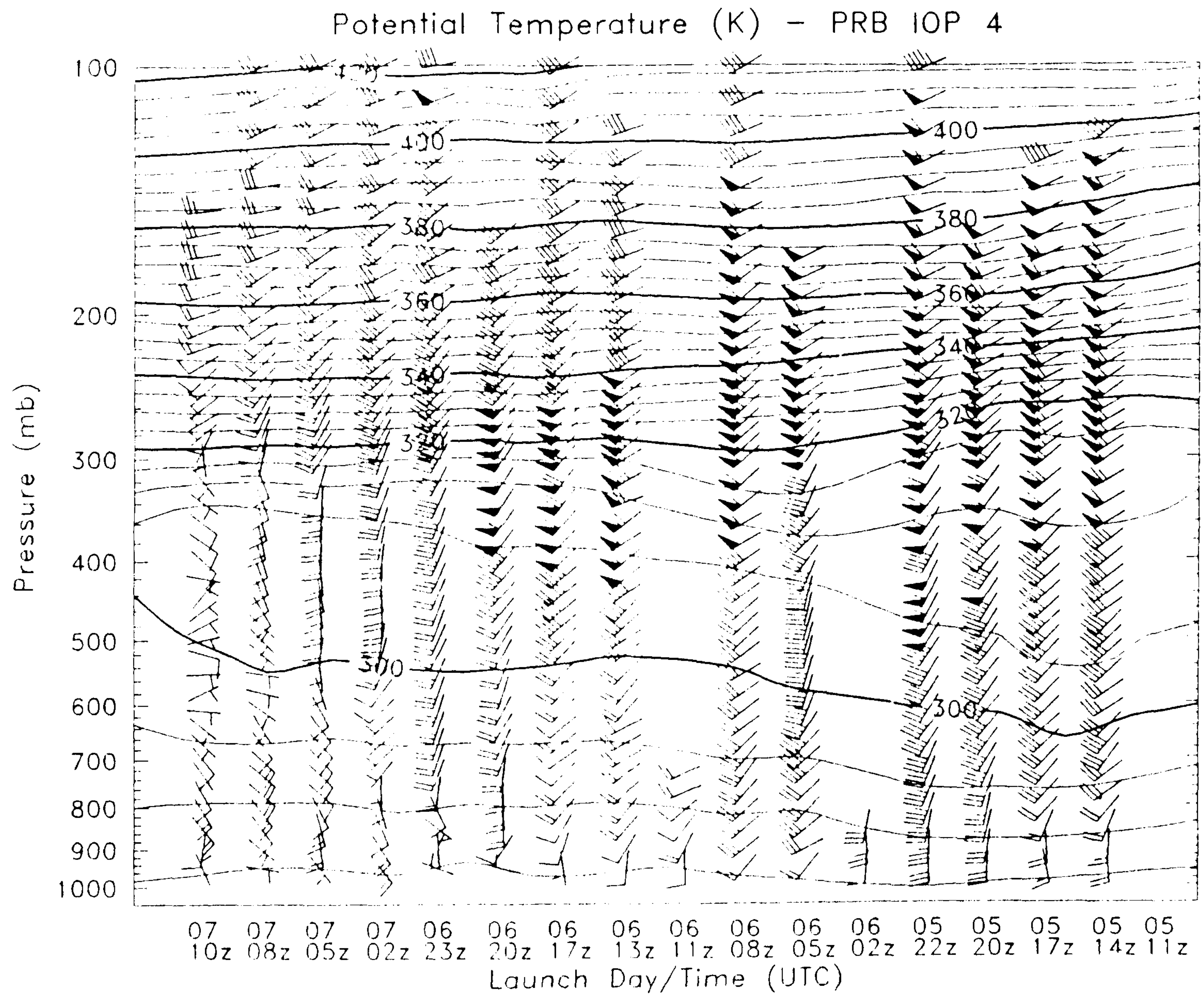

Fig. 13 As in Fig. 3, except for Paso Robles (PRB)

l. **Vandenberg, CA (VBG)**

Observations from the regular U.S. Air Force rawinsonde station VBG were received in the form of printed outputs at 200-foot increments during each launch. A scanner was used to digitize these printouts up to the 100 mb level. Significant and mandatory levels were also scanned and digitized. Geopotential heights were recalculated to make then compatible with those from the MRS and Digicora. In the analysis, a minimum pressure was set at 20 mb.

Table 15 is a list of launch dates and times, minimum pressure level and maximum altitude reached, and notes related to each launch. Wind vectors from each launch overlaid with contours of potential temperature are shown in Fig. 14 for each Picket Fence IOP.

Table 15 Summary of rawinsonde launches from Vandenberg (VBG)

Date	Time	Min. Press	Max. Alt.	Notes
02/13	0515	20.0	26234	Analysis cutoff at 20 mb.
02/13	0841	96.0	16395	
02/13	1115	48.2	20684	
02/13	1415	25.2	24710	
02/13	1715	20.0	26226	Analysis cutoff at 20 mb.
02/14	1715	20.0	26320	Analysis cutoff at 20 mb.
02/14	2021	20.0	26291	Analysis cutoff at 20 mb.
02/14	2317	20.0	26233	Analysis cutoff at 20 mb.
02/15	0215	49.7	20441	
02/15	0530	34.9	22689	
02/15	0815	44.7	21125	
02/15	1256	52.9	20091	
02/15	1532	30.6	23754	
02/15	1740	66.6	18656	
02/15	2015	20.0	26339	Analysis cutoff at 20 mb.
02/15	2315	20.0	26301	Analysis cutoff at 20 mb.
02/16	0215	20.0	26278	Analysis cutoff at 20 mb.
02/16	0515	39.2	22011	
02/16	0815	20.0	26277	Analysis cutoff at 20 mb.
02/16	1115	26.2	24499	
02/16	1415	81.1	17398	
02/16	1715	20.0	26322	Analysis cutoff at 20 mb.
02/19	2315	20.0	26271	Analysis cutoff at 20 mb.
02/20	0255	53.7	20056	
02/20	0515	25.7	24714	
02/20	0815	28.5	24040	
02/20	1115	30.5	23581	
02/20	1700	23.7	25210	Late launch (15 Z)
02/20	1900	52.6	20222	Late launch (18 Z)
02/20	2100	52.5	20224	
02/20	2210	53.0	20138	Extra launch.
02/20	2341	62.7	19095	
03/05	1115	35.7	22564	
03/05	1415	20.0	26324	Analysis cutoff at 20 mb.
03/05	1715	20.0	26325	Analysis cutoff at 20 mb.
03/05	2033	20.0	26427	Analysis cutoff at 20 mb.
03/05	2337	20.0	26352	Analysis cutoff at 20 mb.
03/06	0236	33.2	23070	
03/06	0515	20.0	26325	Analysis cutoff at 20 mb.
03/06	0815	30.3	23622	
03/06	1115	20.0	26290	Analysis cutoff at 20 mb.
03/06	1442	20.0	26384	Analysis cutoff at 20 mb.
03/06	1715	20.0	26395	Analysis cutoff at 20 mb.
03/06	2015	20.0	26397	Analysis cutoff at 20 mb.
03/07	0008	38.5	22209	
03/07	0215	20.0	26356	Analysis cutoff at 20 mb.
03/07	0515	20.0	26360	Analysis cutoff at 20 mb.
03/07	0815	20.0	26346	Analysis cutoff at 20 mb.
03/07	1115	20.0	26322	Analysis cutoff at 20 mb.

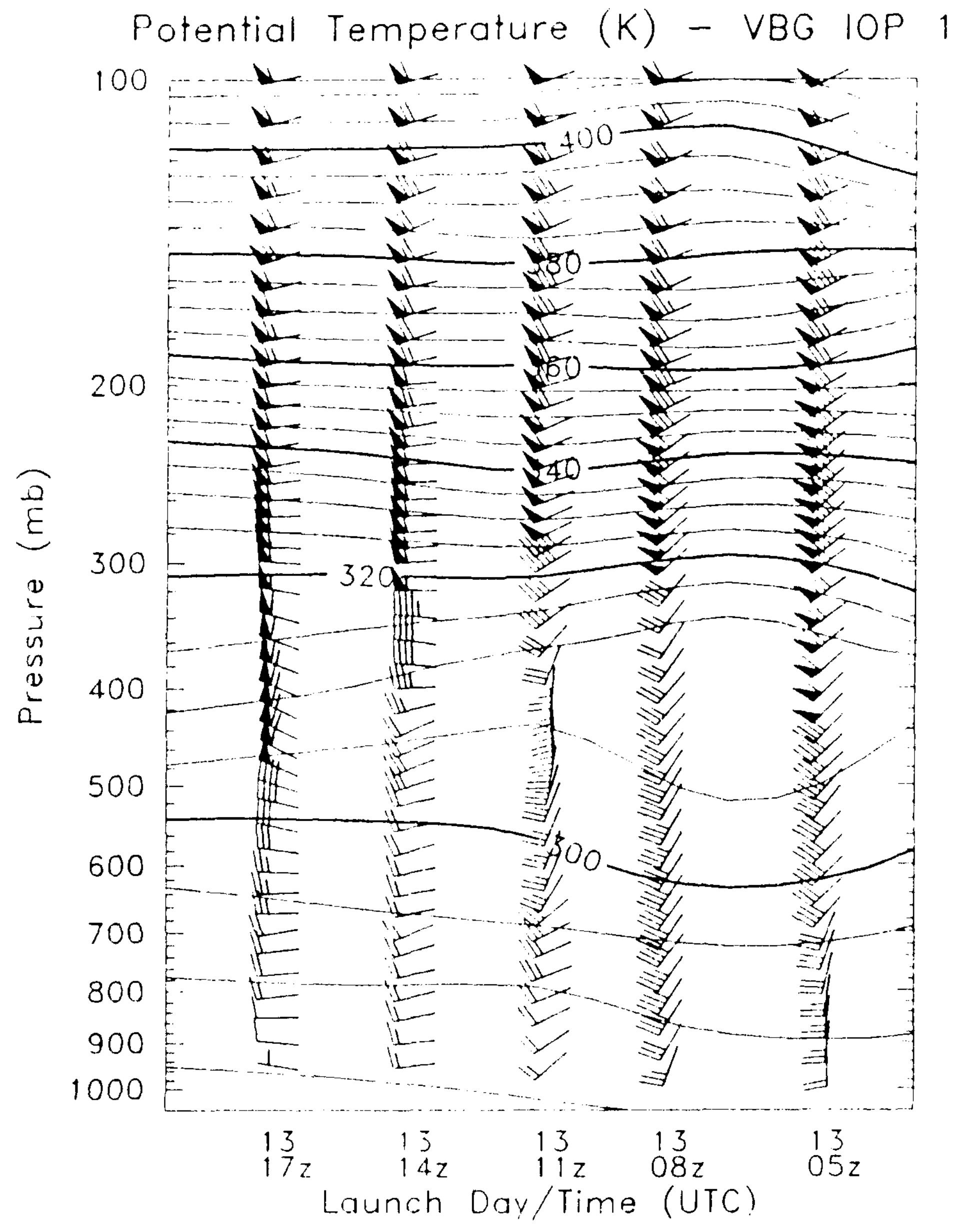

Fig. 14 As in Fig. 3, except for Vandenberg (VBG).

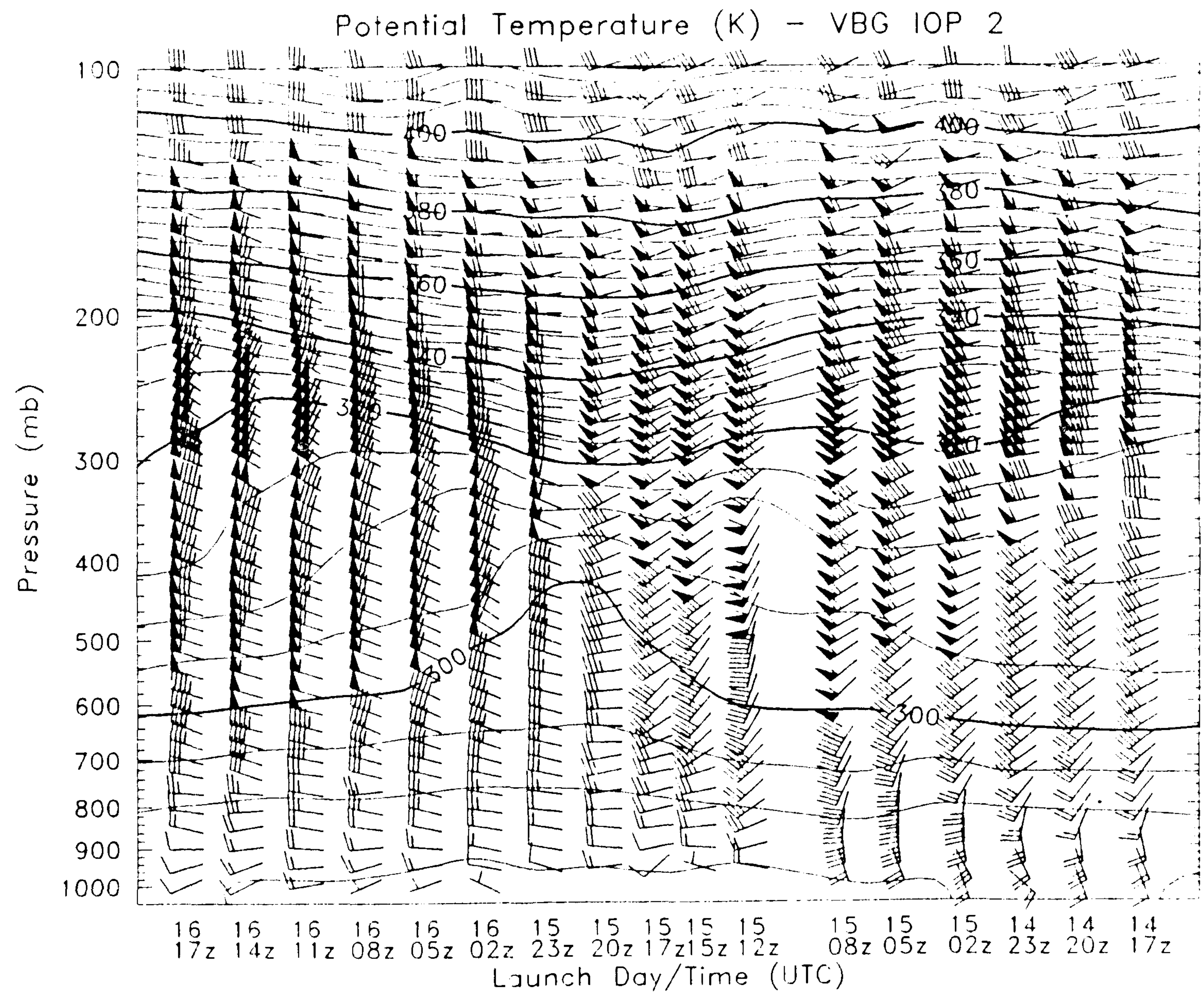

Fig. 14 As in Fig. 3, except for Vandenberg (VBG).

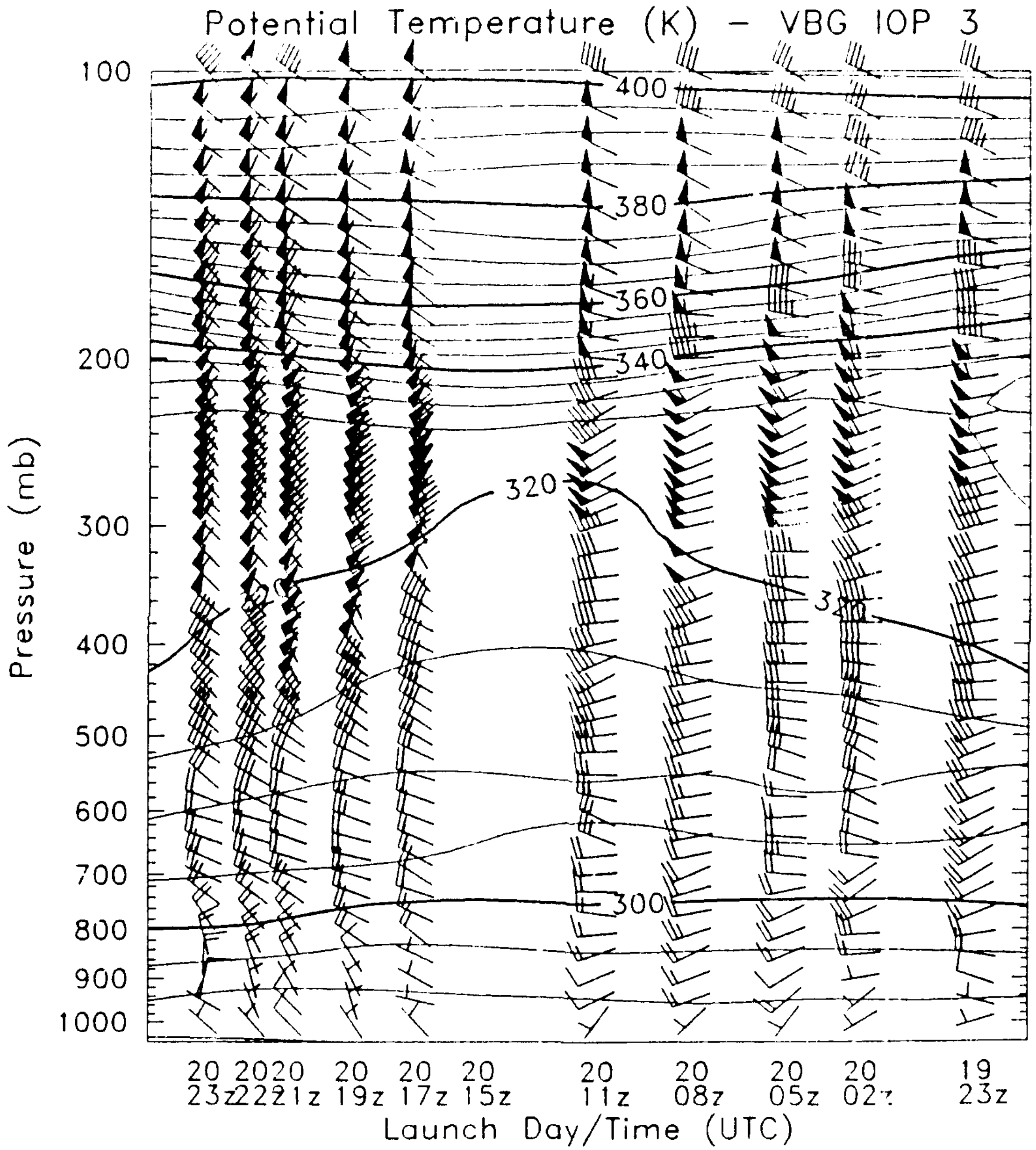

Fig. 14 As in Fig. 3, except for Vandenberg (VBG).

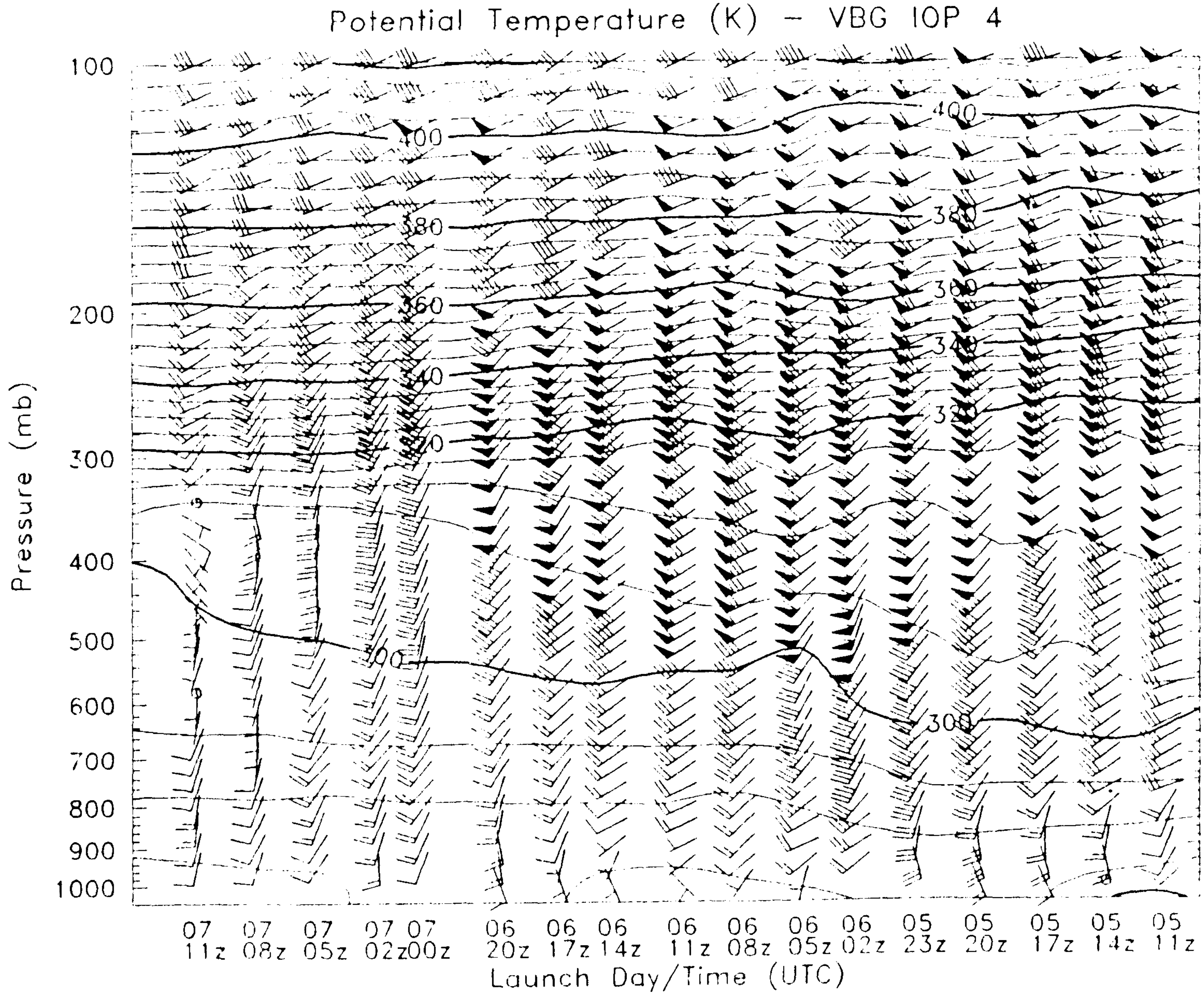

Fig. 14 As in Fig. 3, except for Vandenberg (VBG).

m. **Point Mugu, CA (NTD)**

Observations at the special Picket Fence site at the Pacific Missile Test Center in Pt. Mugu were received with 1000-foot resolution between levels. Significant and mandatory levels increased the average resolution. Geopotential heights were recalculated, making them compatible with MRS and Digicora processed heights.

Table 16 is a list of launch dates and times, minimum pressure level and maximum altitude reached, and notes related to each launch. Wind vectors from each launch overlaid with contours of potential temperature are illustrated in Fig. 15 for each Picket Fence IOP.

Table 16 Summary of rawinsonde launches from Point Mugu (NTD)

Date	Time	Min. Press	Max. Alt.	Notes
02/13	0614	52.5	20193	
02/13	0921	261.2	9989	
02/13	1206	36.5	22453	
02/13	1458	38.2	22193	
02/13	1804	20.0	26267	Analysis cutoff at 20 mb.
02/14	1759	20.0	26265	Analysis cutoff at 20 mb.
02/14	2058	20.0	26254	Analysis cutoff at 20 mb.
02/14	2352	20.0	26304	Analysis cutoff at 20 mb.
02/15	0302	20.0	26296	Analysis cutoff at 20 mb.
02/15	0604	20.0	26308	Analysis cutoff at 20 mb.
02/15	0901	20.0	26329	Analysis cutoff at 20 mb.
02/15	1156	51.4	20331	
02/15	1457	33.5	23021	
02/15	1757	20.0	26343	Analysis cutoff at 20 mb.
02/15	2057	20.0	26347	Analysis cutoff at 20 mb.
02/15	2358	20.0	26369	Analysis cutoff at 20 mb.
02/16	0255	40.5	21811	
02/16	0557	223.6	10988	
02/16	0904	20.0	26363	Analysis cutoff at 20 mb.
02/16	1154	20.0	26329	Analysis cutoff at 20 mb.
02/16	1500	-----	-----	No launch recorded.
02/16	1800	-----	-----	No launch recorded.
02/19	2357	20.0	26325	Analysis cutoff at 20 mb.
02/20	0258	40.5	21850	
02/20	0558	124.9	14910	
02/20	0858	41.0	21769	
02/20	1158	62.7	19144	
02/20	1458	20.0	26287	Analysis cutoff at 20 mb.
02/20	1807	20.0	26306	Analysis cutoff at 20 mb.
02/20	2108	20.0	26386	Analysis cutoff at 20 mb.
02/20	2354	20.0	26309	Analysis cutoff at 20 mb.
03/05	0947	33.0	23121	
03/05	1157	34.9	22777	
03/05	1457	20.0	26332	Analysis cutoff at 20 mb.
03/05	1757	20.0	26390	Analysis cutoff at 20 mb.
03/05	2057	20.0	26401	Analysis cutoff at 20 mb.
03/05	2358	20.0	26261	Analysis cutoff at 20 mb.
03/06	0259	154.8	13400	
03/06	0559	20.0	26323	Analysis cutoff at 20 mb.
03/06	0900	65.5	18839	
03/06	1200	38.7	22127	
03/06	1459	20.0	26340	Analysis cutoff at 20 mb.
03/06	1753	20.0	26352	Analysis cutoff at 20 mb.
03/06	2054	20.0	26413	Analysis cutoff at 20 mb.
03/06	2359	20.0	26295	Analysis cutoff at 20 mb.
03/07	0253	20.0	26418	Analysis cutoff at 20 mb.
03/07	0558	20.0	26328	Analysis cutoff at 20 mb.
03/07	0901	20.0	26366	Analysis cutoff at 20 mb.
03/07	1200	20.0	26363	Analysis cutoff at 20 mb.

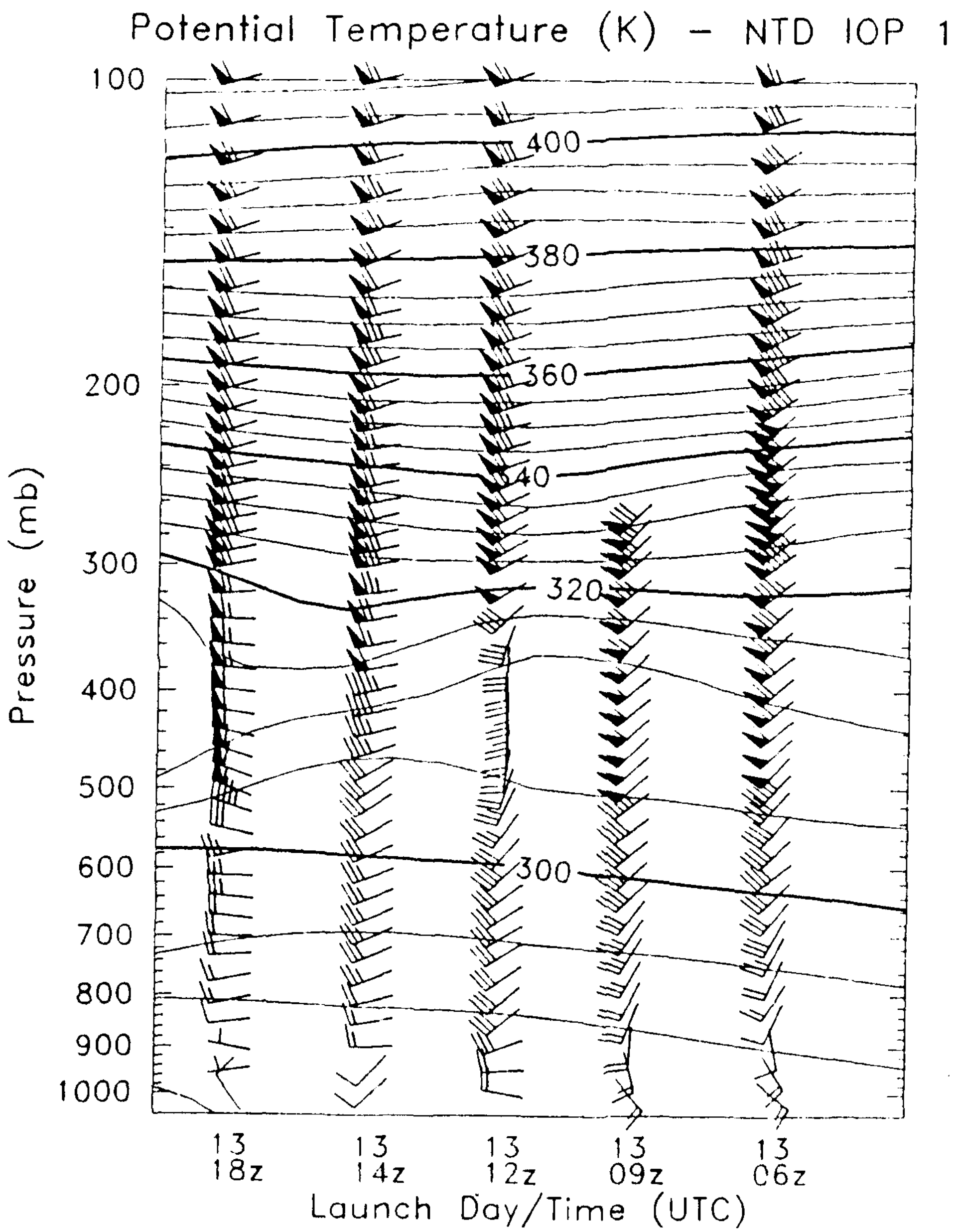

Fig. 15 As in Fig. 3, except for Point Mugu (NTD).

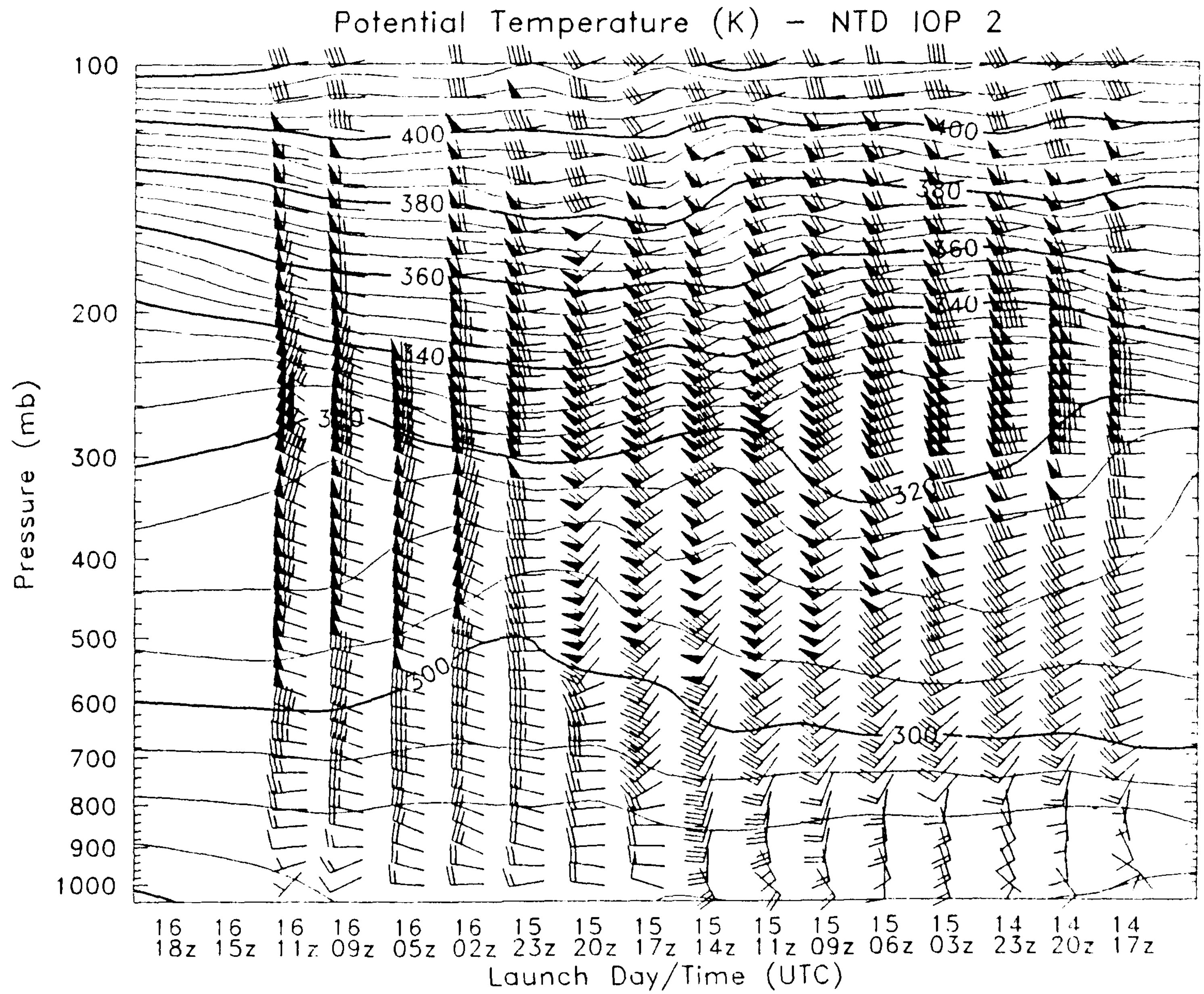

Fig. 15 As in Fig. 3, except for Point Mugu (NTD).

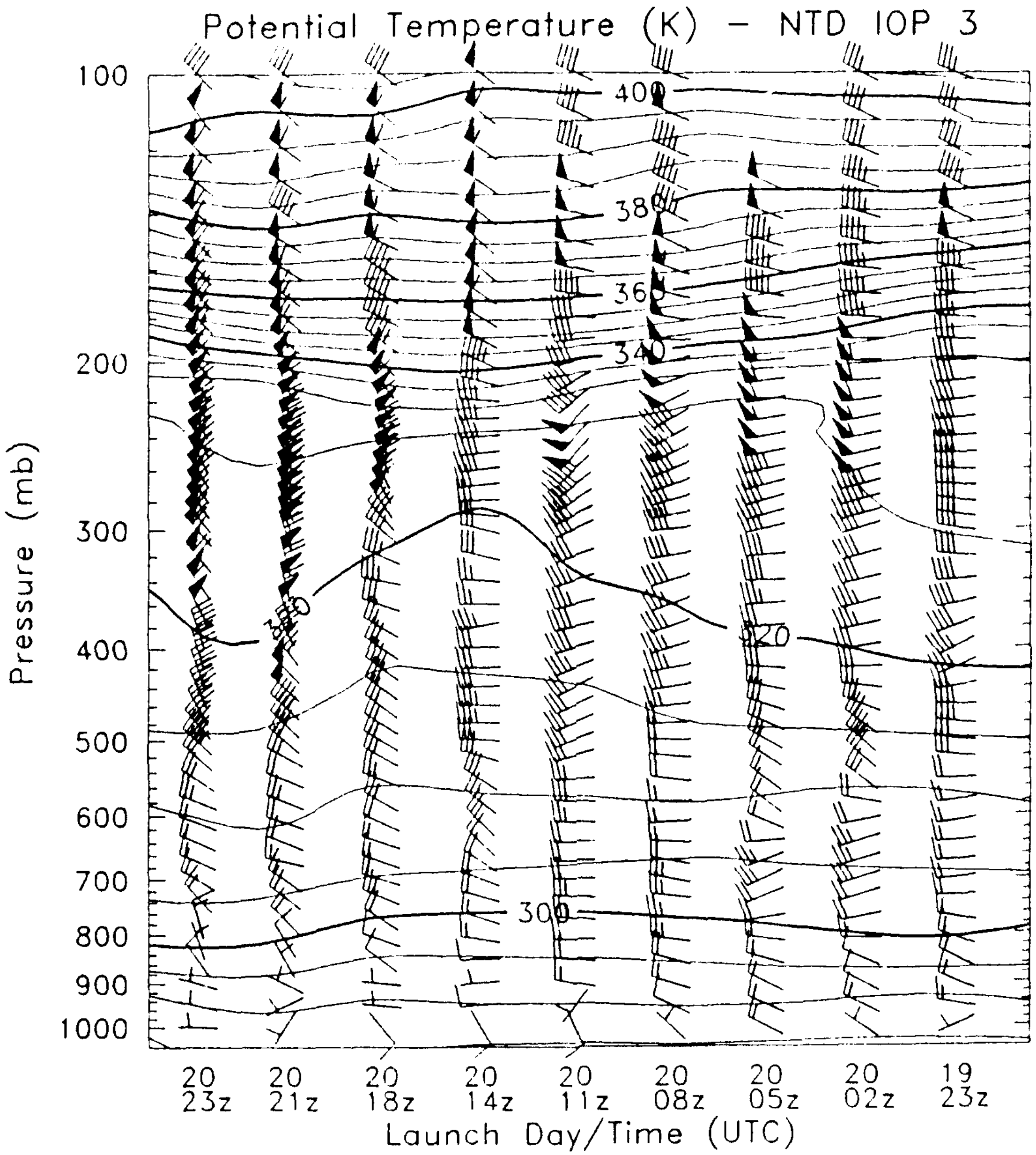

Fig. 15 As in Fig. 3, except for Point Mugu (NTD).

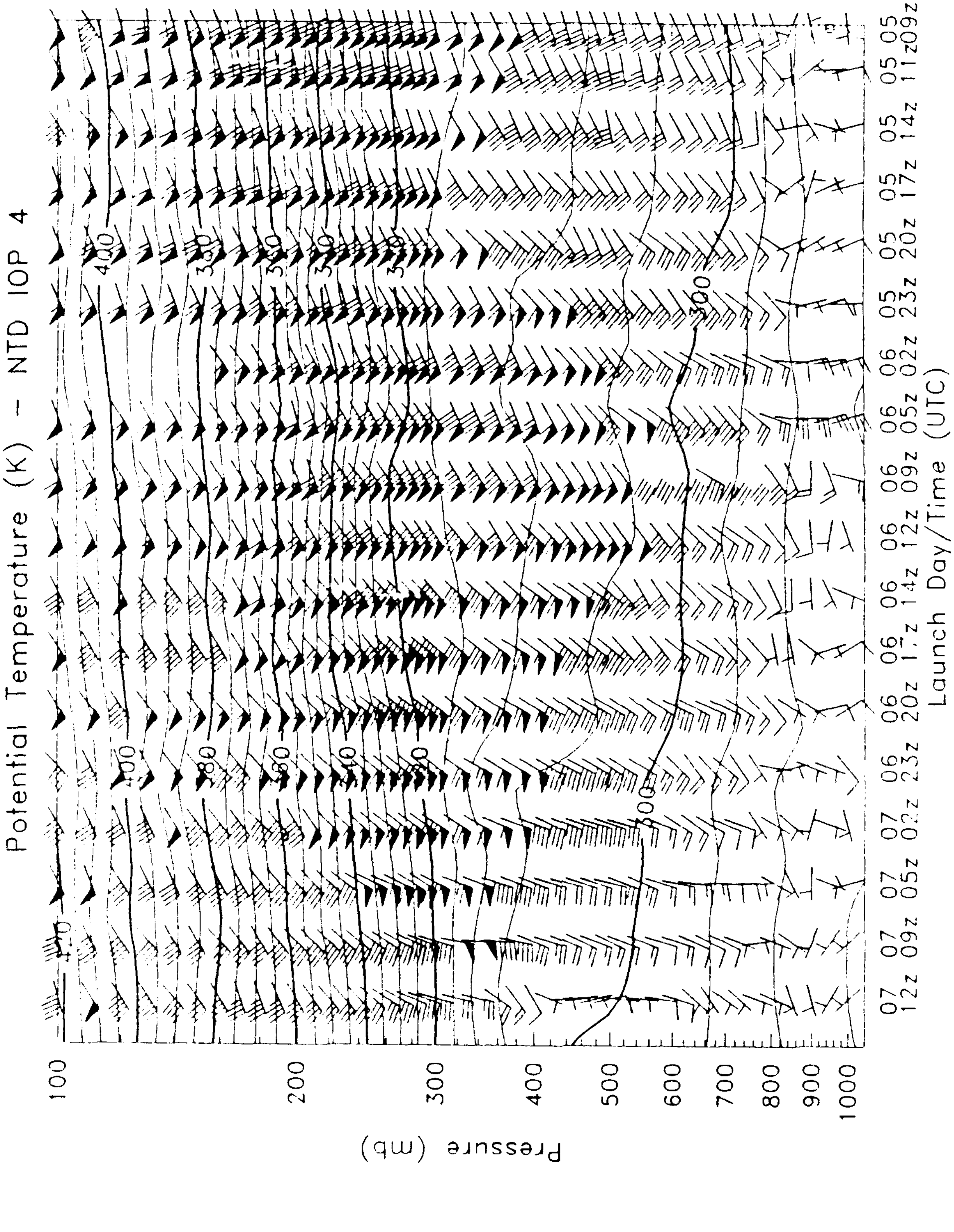

Fig. 15 As in Fig. 3, except for Point Mugu (NTD).

n. **San Diego, CA (NKX)**

Soundings from the regular NWS rawinsonde site in San Diego were processed by NCAR. Table 17 is a list of launch times, minimum pressure and maximum altitudes reached, and special notes related to each launch. Wind vectors and contours of potential temperature are given in Fig. 16 for each Picket Fence IOP.

Table 17 Summary of rawinsonde launches from San Diego (NKX)

Date	Time	Min. Press.	Max. Alt.	Notes
02/13	0505	131	14573	Weak signal.
02/13	0810	138	14298	Weak signal.
02/13	1101	178	12274	Weak signal.
02/13	1402	100	16294	
02/13	1705	100	16510	
02/14	1705	32	23346	
02/14	2000	201	11751	Weak signal.
02/14	2300	8	32728	
02/15	0206	97	16380	
02/15	0502	96	16437	
02/15	0805	97	16367	
02/15	1101	51	21428	
02/15	1401	13	29154	
02/15	1706	96	16494	
02/15	2001	112	15[illegible]97	Sonde failure.
02/15	2259	23	25620	Bad winds below 750 mb.
02/16	0159	594	4252	Weak signal. Bad winds.
02/16	0507	138	14127	Weak signal.
02/16	0805	114	15312	Sonde failure.
02/16	1101	21	26064	
02/16	1406	96	16419	
02/16	1700	98	16294	
02/19	2310	258	10593	Weak signal.
02/20	0203	95	16586	
02/20	0500	95	16638	
02/20	0814	98	16441	
02/20	1101	476	6130	Sonde failure.
02/20	1403	95	16620	
02/20	1705	99	16397	
02/20	2004	96	16585	
02/20	2301	22	25512	
03/05	1107	8	32309	
03/05	1500	---	-----	No launch recorded.
03/05	1709	94	16662	
03/05	2001	96	16590	
03/06	2300	13	30809	
03/06	0210	96	16537	Bad winds above 850 mb.
03/06	0500	93	16723	
03/06	0802	98	16415	
03/06	1103	7	33507	
03/06	1415	94	16644	
03/06	1702	96	16549	
03/06	2005	97	16521	
03/06	2300	8	32296	
03/07	0200	98	16327	
03/07	0506	100	16275	
03/07	0900	93	-----	No data file from NCAR.
03/07	1101	20	26438	

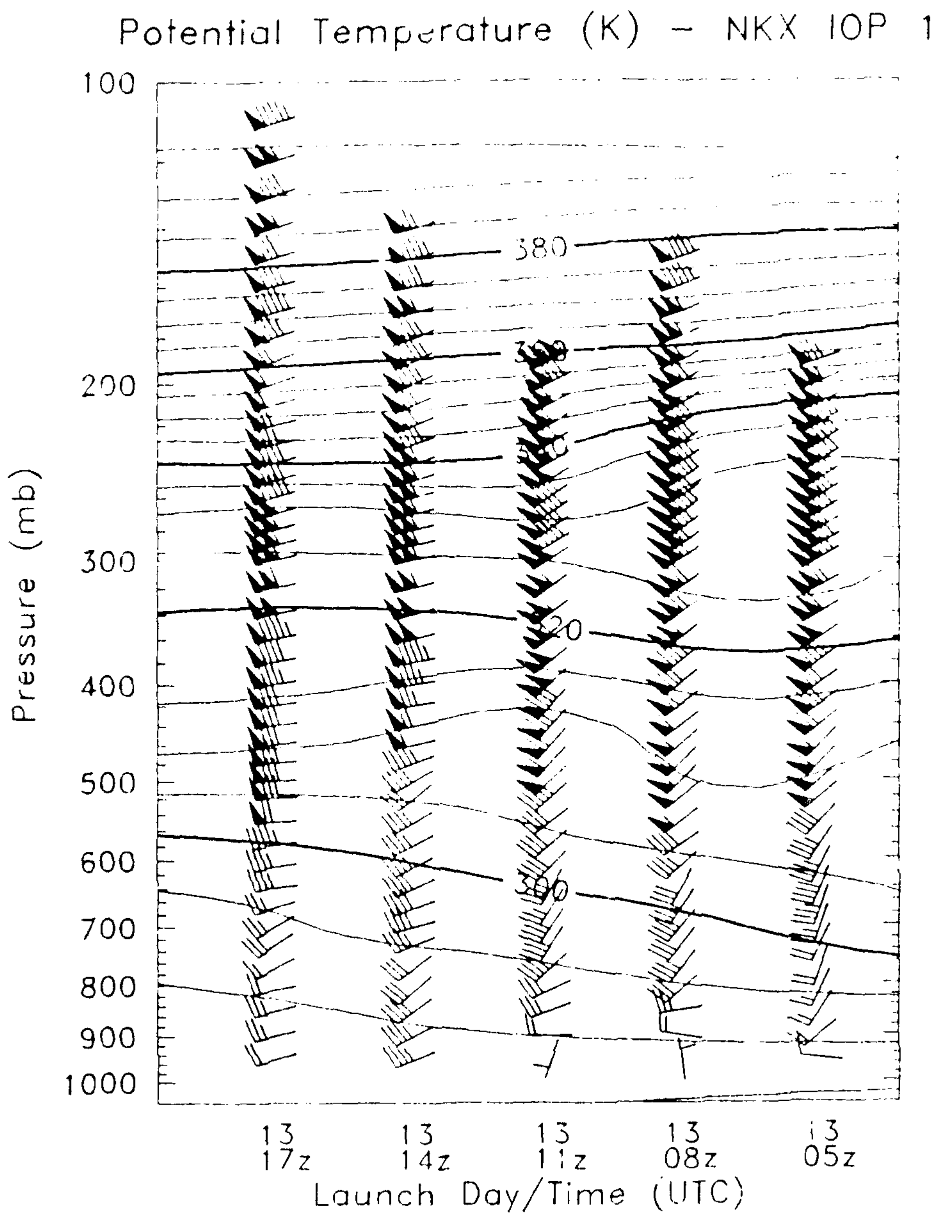

Fig. 16 As in Fig. 3, except for San Diego (NKX).

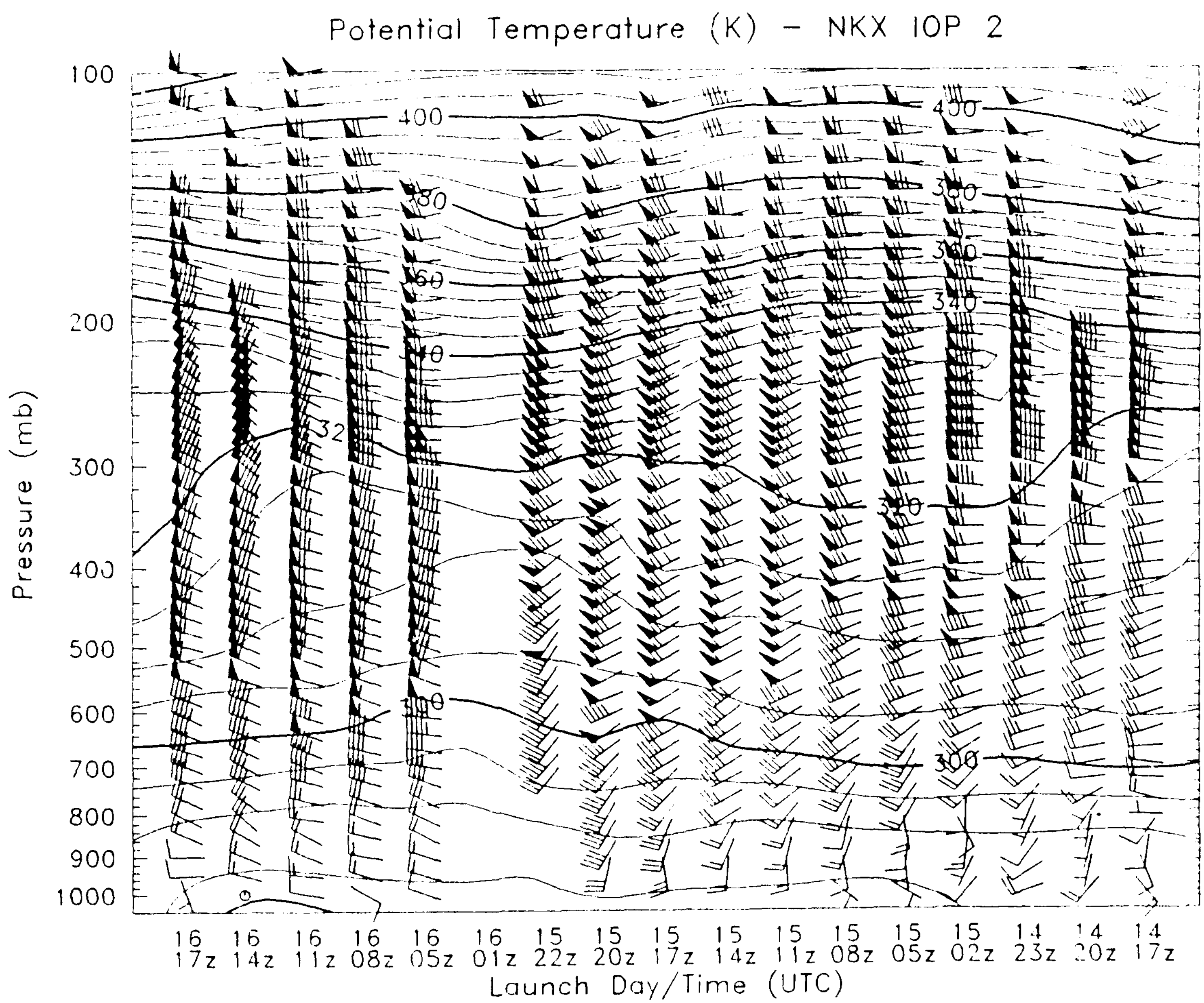

Fig. 16 As in Fig. 3, except for San Diego (NKX).

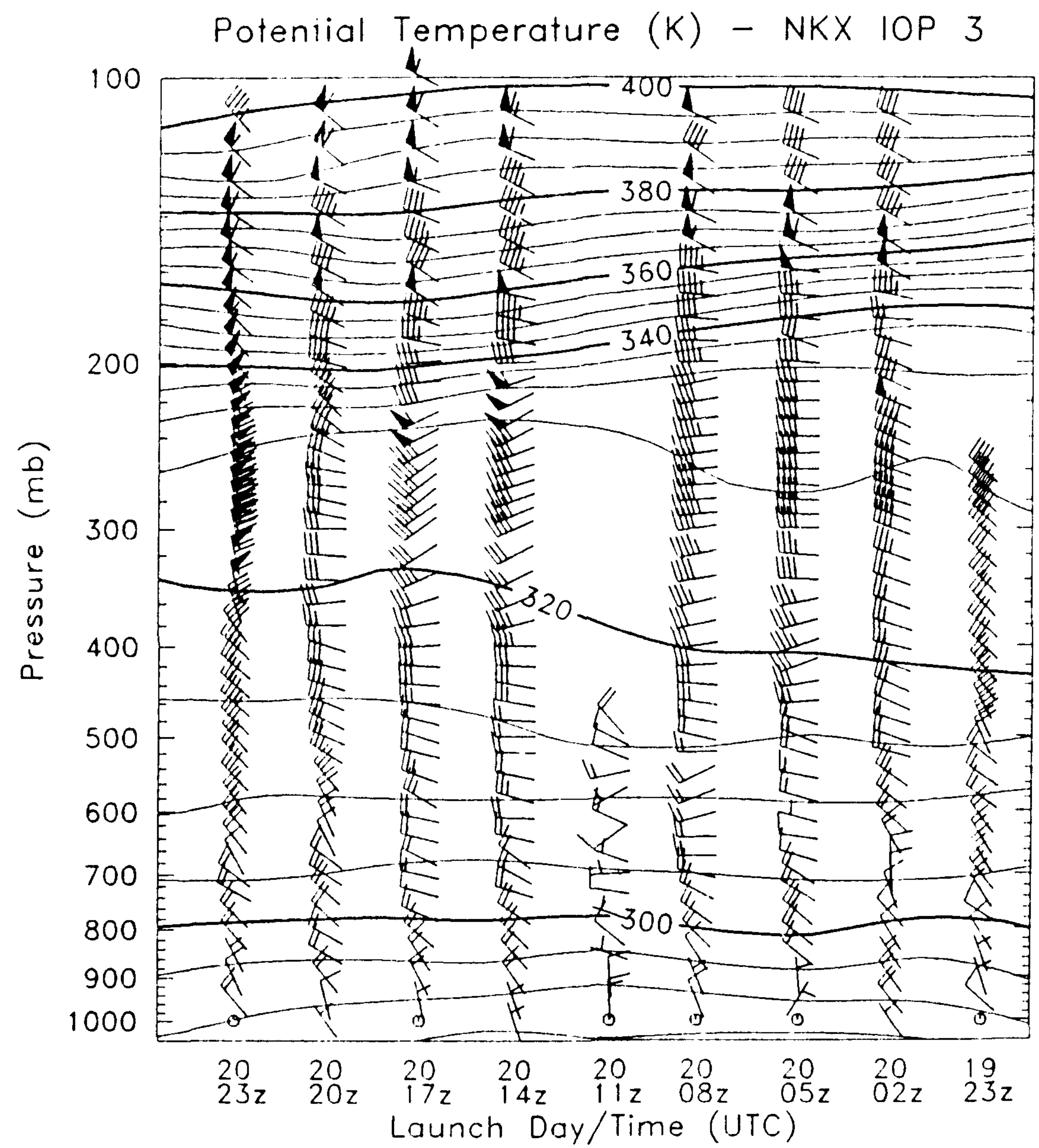

Fig. 16 As in Fig. 3, except for San Diego (NKX).

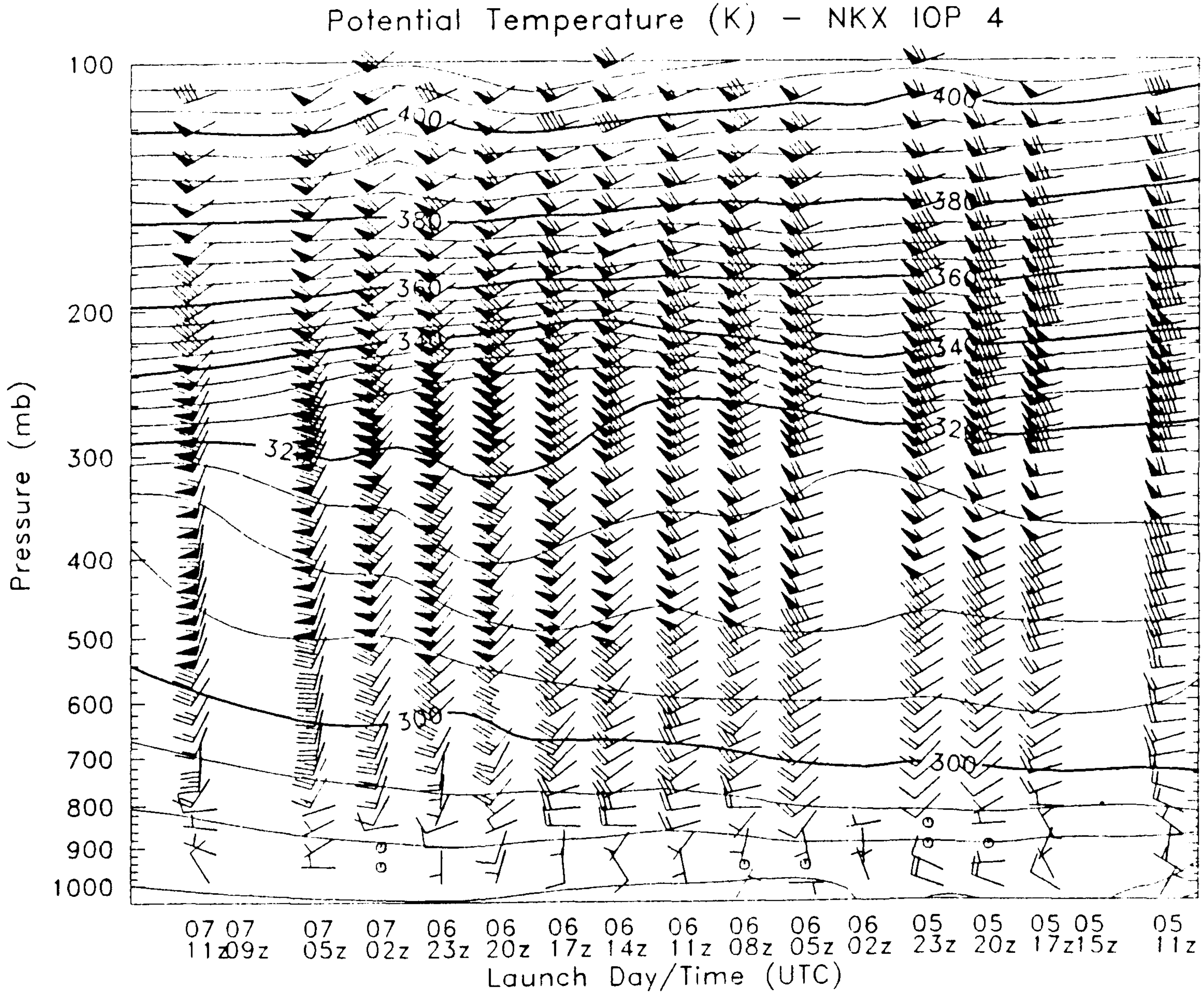

Fig. 16 As in Fig. 3, except for San Diego (NKX).

4. INTENSIVE OBSERVATION PERIOD (IOP) SUMMARIES

Table 18 Picket Fence IOP beginning and termination times.

Picket Fence IOP	Beginning Time	Termination Time	Associated STORM-FEST IOP
1	06 UTC 13 Feb	18 UTC 13 Feb	6
2	18 UTC 14 Feb	18 UTC 16 Feb	7, 8
3	00 UTC 20 Feb	00 UTC 21 Feb	9, 10
4	12 UTC 05 Mar	12 UTC 07 Mar	17

The primary objective of the Picket Fence experiment was to determine whether a more accurate specification of upstream boundary conditions along the U.S. West Coast, through higher temporal and spatial resolution upper-air observations, will improve the prediction of mesoscale systems observed over the Central U.S. during STORM-FEST. Consequently, a Picket Fence Intensive Observation Period (PIOP) was initiated when a disturbance (e.g., mid-level short wave) was expected to cross the Picket Fence domain and subsequently contribute to mesoscale development (e.g., frontogenesis) over the STORM-FEST region (Fig. 2). As shown in Table 18 above, each PIOP was followed by a STORM-FEST IOP (SIOP), which commenced when mesoscale development began within the STORM-FEST region. Each SIOP began 24-36 h after the PIOP start time. Ideally, special 6-h National Weather Service (NWS) soundings would have been made over the Intermountain Region downstream (upstream) of the Picket Fence (STORM-FEST) domain to ensure spatial continuity (see Fig. 2). Such highly coordinated observations between the two experiments occurred only during PIOPs 2 and 4.

The NWS and special sites along the Picket Fence required 24-h notice before the start of a PIOP. This operational constraint, along with the scientific criteria that disturbances cross the Picket Fence domain and later become

associated with mesoscale development over the Central U.S., necessitated that Picket Fence alerts be based on 84-h to 120-h forecasts (see Fig. 2). These forecasts were highly dependent on numerical guidance provided by the National Meteorological Center (NMC) T126, Fleet Numerical and Oceanographic Center (FNOC) T79 and the European Center for Medium-range Weather Forecasting (ECMWF) T213 global forecast models. Aside from miscellaneous technical problems, the inaccuracy and run-to-run variability of this medium-range (> 72 h) numerical guidance, initialized over the data-sparse Pacific Ocean, led to challenging forecasting situations during the experiment. The uncertainty of these forecasts hampered not only the start times of the PIOPs but also the coordination between Picket Fence and STORM-FEST during PIOPs 1 and 3, and to a lesser degree during PIOP 4. During both PIOPs 1 and 3, a decision to commence the PIOP had to made before STORM-FEST was prepared to commit to an SIOP. In general, STORM-FEST personnel preferred to delay the decision to initiate an SIOP until shorter range, more accurate numerical guidance that was initialized after disturbances had crossed the West Coast was available. Although the short-range forecasts correctly showed the eventual development (nondevelopment) over the Central U.S. of the disturbance associated with PIOP 1 (PIOP 3), the later decision by STORM-FEST precluded activation of the intermountain soundings.

Despite these difficulties, the observations taken during the four PIOPs and the associated SIOPs will provide data necessary to test the working scientific hypothesis of the Picket Fence Experiment. That is, a high-resolution quasi-linear array of observing systems upstream (e.g., along the U.S. West Coast) from a domain of interest (e.g., the Central U.S.) improves the observational accuracy of the environmental flow conditions entering that domain and the prediction of the mesoscale circulations that develop within it. In addition, the high-resolution observations collected during the IOPs will provide important data for in-depth case

study analyses of such mesoscale systems. Synoptic overviews and other details concerning each PIOP are provided in the individual summaries below.

a. PIOP 1

(0600 UTC 13 February - 1800 UTC 13 February)

Summary

The feature of interest during Picket Fence IOP 1 (PIOP 1) was a rapidly propagating short wave in the southern branch of the jet stream. The 500 mb vorticity maximum associated with this wave crossed the California coast near Vandenberg around 1500 UTC 13 February 1992. Lee-side cyclogenesis subsequently took place in southeastern Colorado around 0600 UTC 14 February. Although the surface cyclogenesis was not intense, there were mesoscale features accompanying this system that should prove of interest to study. Unfortunately, there was only a limited STORM-FEST IOP (SIOP 6) and no special 6-h NWS soundings were taken in the Intermountain region.

Synoptic Discussion

The mid- to upper-level flow regime over the eastern Pacific Ocean and western U.S. during the first half of February 1992 was characterized by a persistent ridge over the Intermountain region, and a series of troughs over the Gulf of Alaska that slowly migrated southeastward and closed off just west of the California coast. These lows were associated with developing splits in the flow that were typical of the entire experiment period. This flow pattern resulted in a polar jet stream generally positioned north of the Picket Fence across southwestern Canada and a subtropical jet stream located south of the Picket Fence across northern Mexico and the Gulf of Mexico. The polar and subtropical flows tended to merge downstream in a deep low-trough system situated over eastern Canada and the U.S., which was associated with several Atlantic coastal surface lows and arctic outbreaks over the Great Plains and upper Mississippi Valley.

Generally, the Pacific closed-low systems gradually moved inland in the southern branch of the flow, undercut the ridge over the Rockies, weakened, and

eventually became associated with weak sea-level disturbances along the Gulf coast that spread some overrunning precipitation into the STORM-FEST region. Later in the month each succeeding Pacific low tended to close off farther north, which enabled the southern stream and embedded short wave disturbances to migrate farther northward into California across the Picket Fence, and then into the Central U.S.

On 0000 UTC 11 February, a series of 500 mb short wave impulses, rotating around the base of a deteriorating closed low centered near 45^{o} N, 135^{o} W, approached the Central California coast but weakened in the diffluent flow upstream of the intermountain ridge. On 1200 UTC 12 February, a more robust short wave was present upstream of the closed low center that was now beginning to open and split, with the northern portion of the trough receding northward and the southern portion becoming mobile in the southern branch flow. This southern trough was later reinforced by the upstream short wave and became the subject of PIOP 1.

The retreating northern portion of the trough was off the Queen Charlotte Islands and the southern branch trough was along 130^{o} W on 0000 UTC 13 February, six hours before the start of PIOP 1 (Fig. 17). The 500 mb vorticity maximum associated with this disturbance crossed the California coast near Vandenberg (34^{o} N, 120^{o} W) around 1500 UTC 13 February with an associated 56 m s^{-1} jet streak at 260 mb over southern California and northern Baja, Mexico (Fig. 18). Three hours earlier, a special Picket Fence National Weather Service (NWS) observation taken at San Diego, CA (NKX) reported a 290 mb wind of 71 m s^{-1}.

During the next 24 h, the trough moved rapidly eastward (Fig. 19), and was associated with a 1004 mb lee-side surface cyclogenesis in southeastern Colorado by 0600 UTC 14 February. This cyclone and its attendant frontal systems, which eventually became the subject of SIOP 6, propagated east-southeastward and

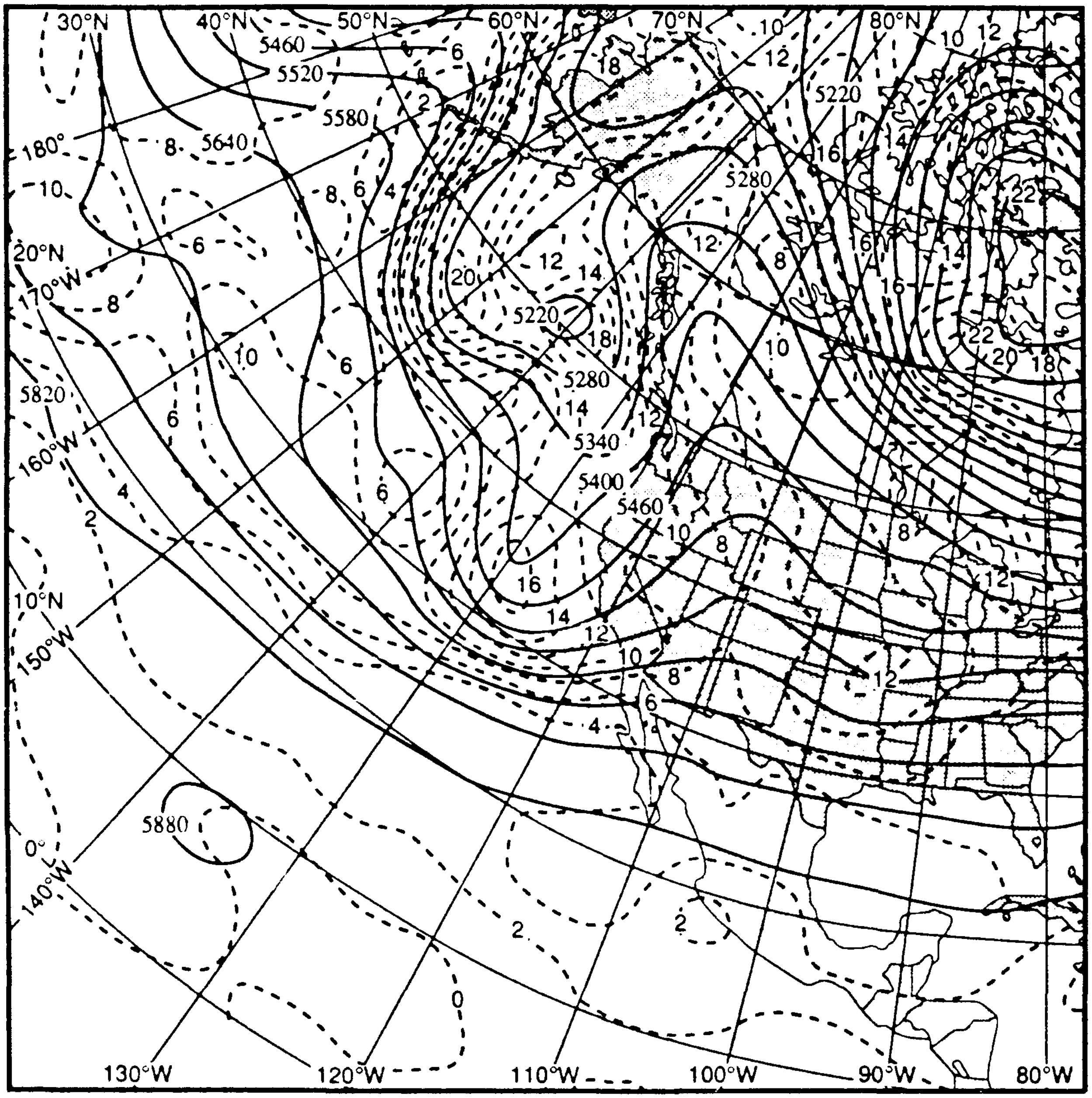

Fig. 17 Analysis of 500 mb height (solid, m) and absolute vorticity (dashed, 10^{-5} s^{-1}) for 0000 UTC 13 February 1992 based on the National Meteorological Center Aviation model analysis.

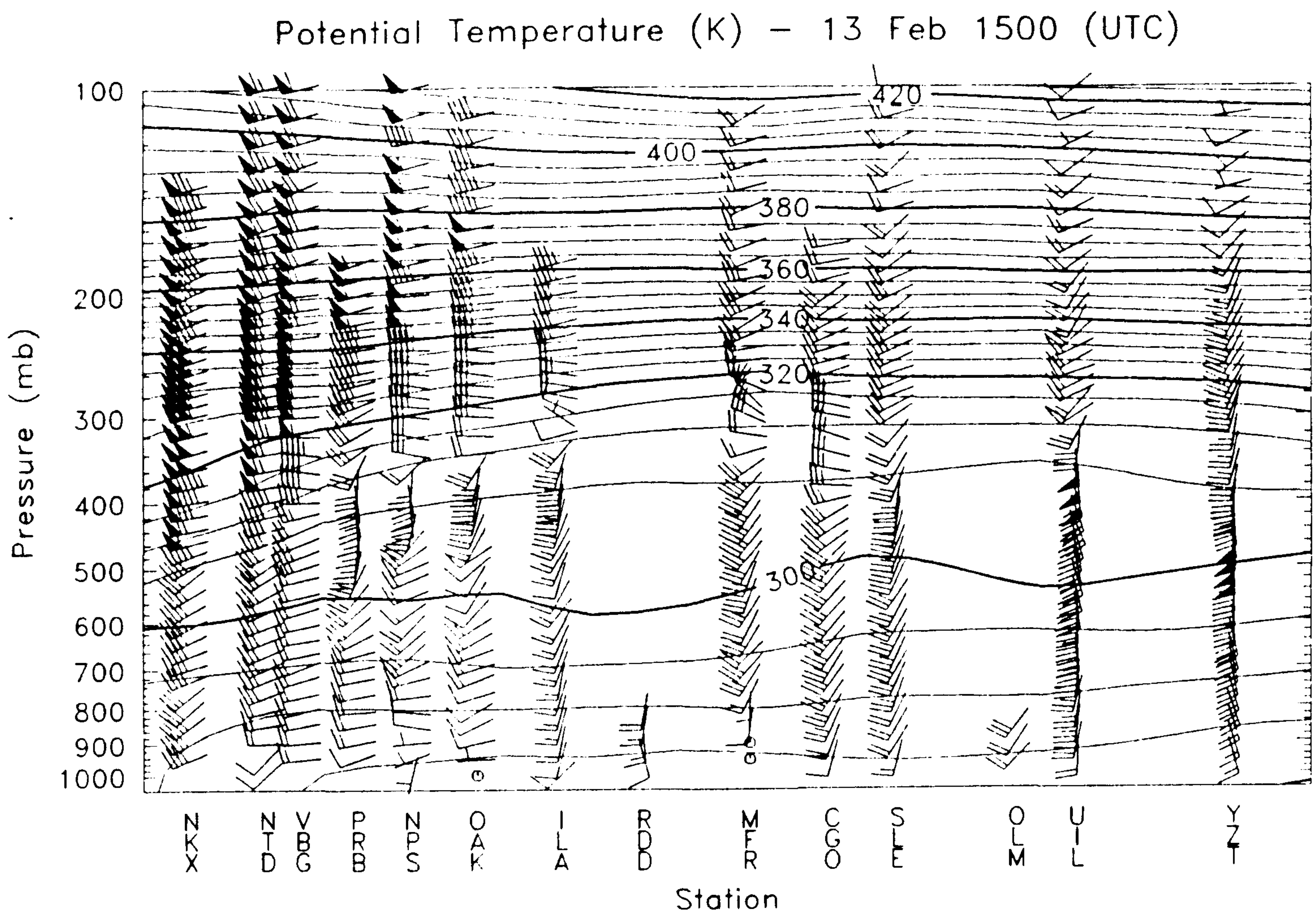

Fig. 18 North-south cross section analysis of theta (solid, K) taken from Port Hardy, Vancouver (YZT) to San Diego, California (NKX) for 1500 UTC 15 February 1992. See Table 1 for explanation of station codes. Wind barbs represent observed wind speeds and directions (flags denote 25 m s^{-1}; whole barbs denote 10 m s^{-1}; half barbs denote 5 m s^{-1}).

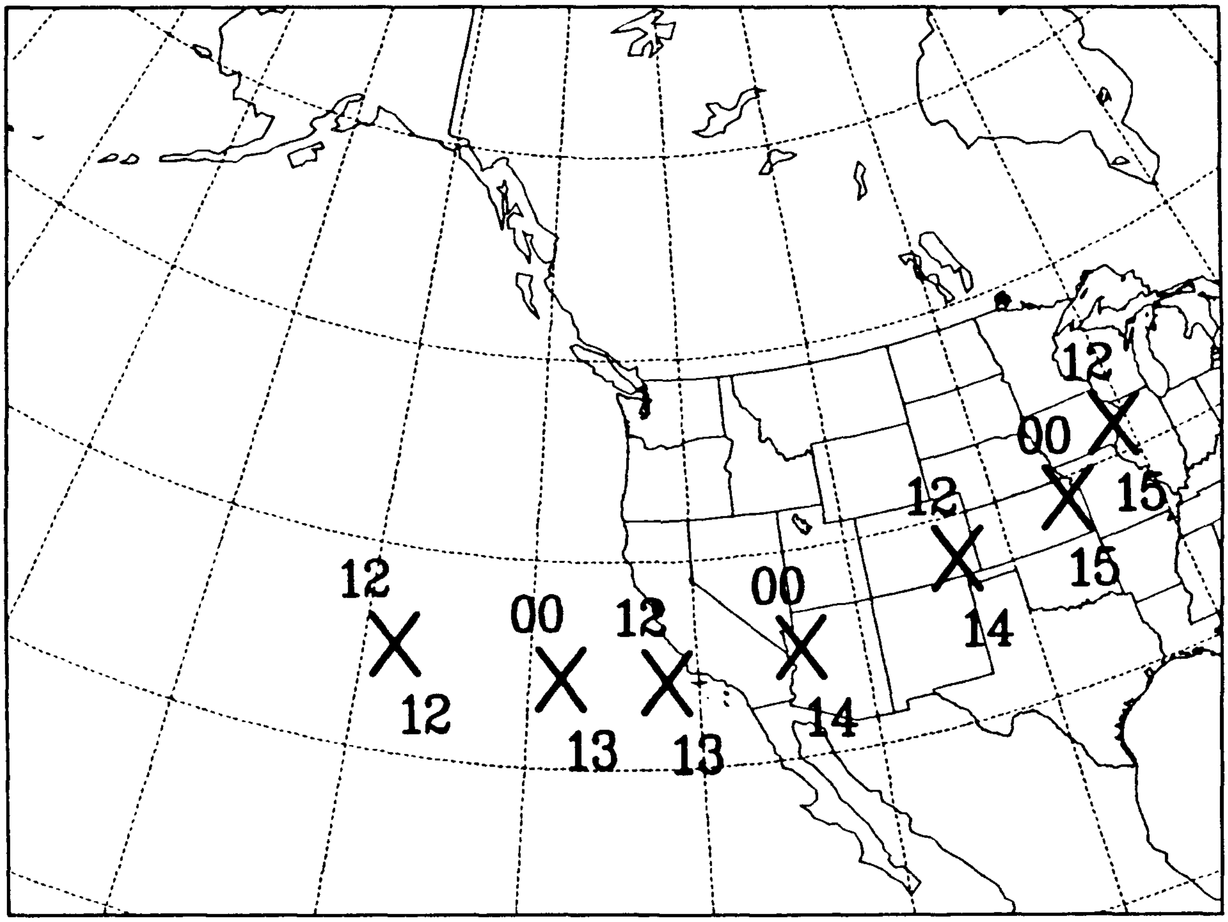

Fig. 19 Track of the 500 mb vorticity maxima observed during PIOP 1 in 12-h increments from 1200 UTC 12 February through 1200 UTC 15 February 1992. The location of the vorticity maxima is denoted by and "X". Numbers to the upper left and lower right of each X denotes UTC hour and date, respectively.

reached its lowest central pressure of 996 mb over the western Oklahoma Panhandle by 1800 UTC 14 February (Fig. 20). Thereafter, the surface low and the upstream 500 mb short wave turned more northeastward and slowly weakened, and moved across Missouri and out of the STORM-FEST domain into Illinois by 1200 UTC 15 February.

This storm system was associated with a wide variety of interesting mesoscale phenomena while it propagated through the STORM-FEST region. Mixed stratiform precipitation remained mainly north of the surface cyclone in Kansas and Missouri while convective outbreaks occurred along the cold front stretching southward through Texas. There were reports of thunder-snow in Missouri and a tornado watch box was issued for southern Missouri and northern Arkansas on 0035 UTC 15 February.

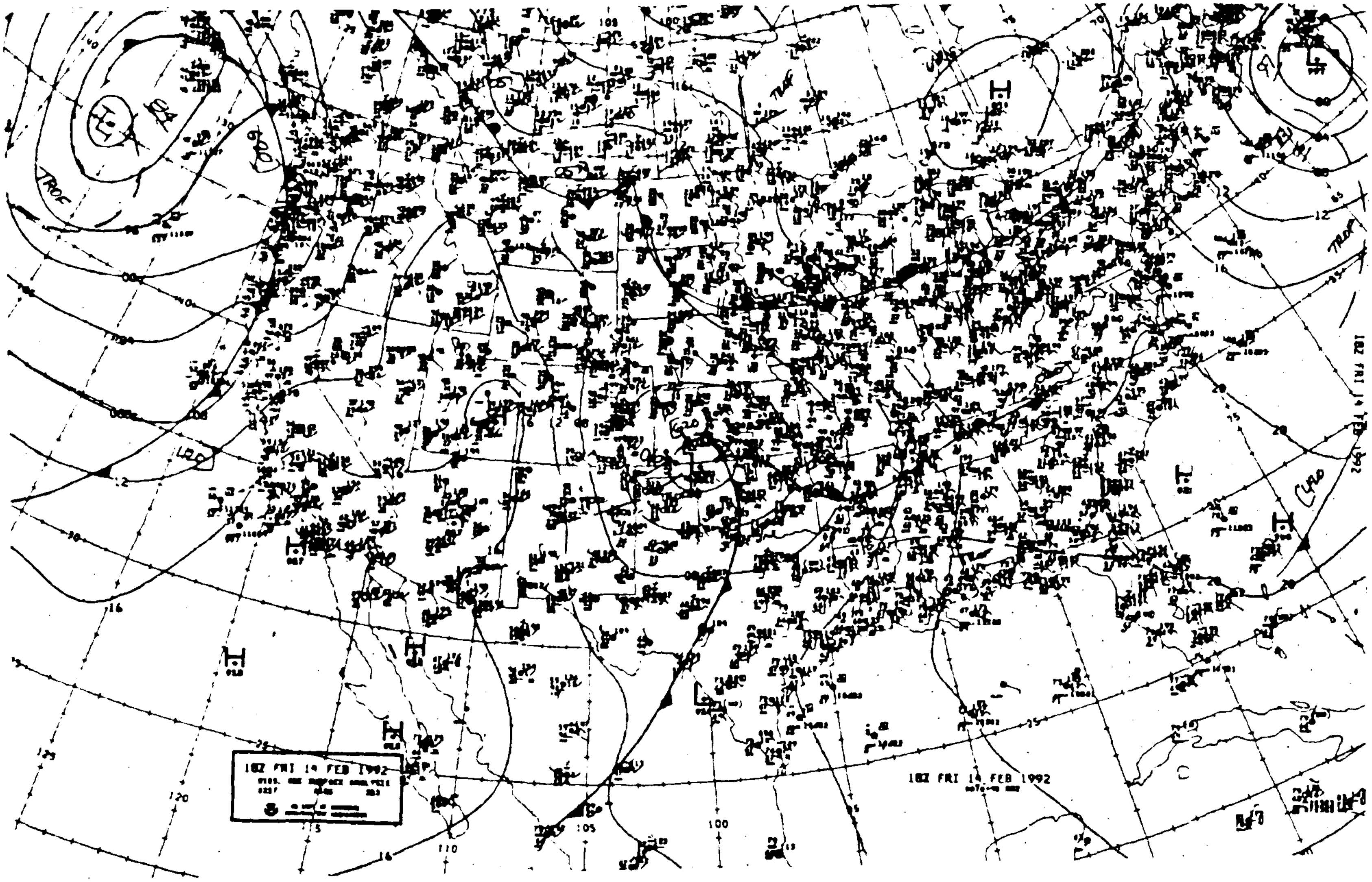

Fig. 20 National Meteorological Center surface chart for 1800 UTC 14 February 1992.

b. PIOP 2

(1800 UTC 14 February - 1800 UTC 16 February)

Summary

The feature of interest during Picket Fence IOP 2 (PIOP 2) was a short-wave trough rotating around a slowly eastward moving closed-low system. The 500 mb vorticity maximum associated with the short wave crossed the West Coast near the Mexico and California border around 0300 UTC 16 February, while the vorticity center associated with the upper low crossed the central Oregon coast around 1800 UTC 16 February. The PIOP was extended six hours to 1800 UTC 16 February for the special Picket Fence sites north of Monterey, California in order to observe the upper low passage. Lee-side cyclogenesis associated with the southern short wave took place in southeastern Colorado around 1800 UTC 16 February. STORM-FEST conducted a full scale IOP (SIOPs 7 and 8) for this system with special 6-h NWS soundings taken in the Intermountain region.

Synoptic Discussion

By the middle of February 1992, the split in the Eastern Pacific flow, which had effectively steered disturbances north and south of the Picket Fence throughout the first half of the month, was located far enough north to enable the passage of a series of short-wave disturbances across the Picket Fence domain. The trough system associated with PIOP 2 was the second of two systems that crossed the West Coast within 48 h. The first wave, which was the subject of PIOP 1, detached from a persistent closed-low system southwest of the Queen Charlotte Islands and became mobile in the southern jet stream. The second wave also rotated around the base of this low but had more thermodynamic support, which enabled it to dig slightly farther south than the first wave.

The short wave was in the base of the long-wave trough along 132° W on 0000 UTC 15 February, six hours after the start of PIOP 2 (Fig. 21). The 500 mb

vorticity maximum associated with this disturbance crossed the coast near the Mexico and California border around 0300 UTC 16 February with an associated 53 m s^{-1} jet streak at 290 mb over southern California and northern Baja, Mexico (Fig. 22). During the next 24 h, the short wave rapidly outran the northern closed low (Fig. 23), which was weakening and moving slowly eastward. The vorticity center associated with this upper low eventually crossed the Oregon coast near 42.5^{o} N around 1800 UTC 16 February. In general, the track of the vorticity center associated with the mobile short wave of PIOP 2 was very similar to the track of PIOP 1(cf. Figs. 19 and 23). A 1003 mb lee-side surface cyclogenesis occurred in southeastern Colorado by 1800 UTC 16 February. This cyclone, which eventually became the subject of SIOPs 7 and 8, propagated slowly east-northeastward and quickly occluded. The low reached a central pressure of 996 mb over western Kansas by 0900 UTC 17 February (Fig. 24). Thereafter, the system turned more northeastward and slowly weakened, and moved across northwestern Missouri and out of the STORM-FEST domain into Illinois by 1800 UTC 18 February.

The medium-range outlook suggested that the storm system eventually observed during PIOP 2 and SIOPs 7 and 8 would be a stronger event than its predecessor observed during PIOP 1 and SIOP 6. For this reason, both the Picket Fence and STORM-FEST resources were saved for the second event. These IOPs were the first successful operation in terms of all three observational domains (Picket Fence, Intermountain Region and STORM-FEST). The coordinated Picket Fence and Intermountain soundings should clearly define the upper-level features entering the STORM-FEST region during SIOP 7. Unfortunately, the first system was more interesting from a weather perspective and slightly more intense. Nevertheless, since PIOP 2 followed PIOP 1 by 24 h, an extensive although not continuous period of observations is available during this interval to study the flux of energy and other properties across the West Coast. Other forecast issues associated

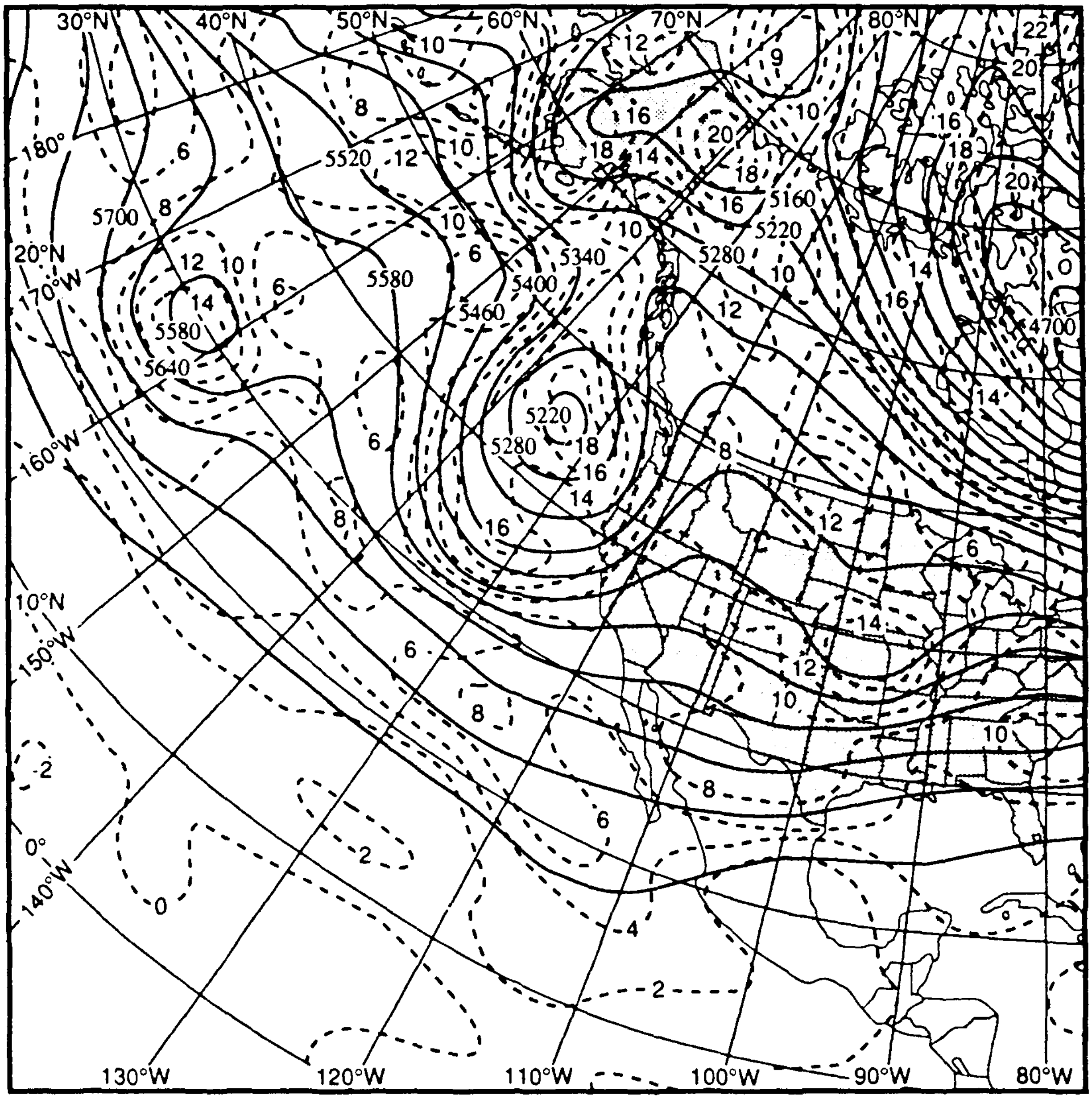

Fig. 21 As in Fig. 17, except for 0000 UTC 15 February 1992.

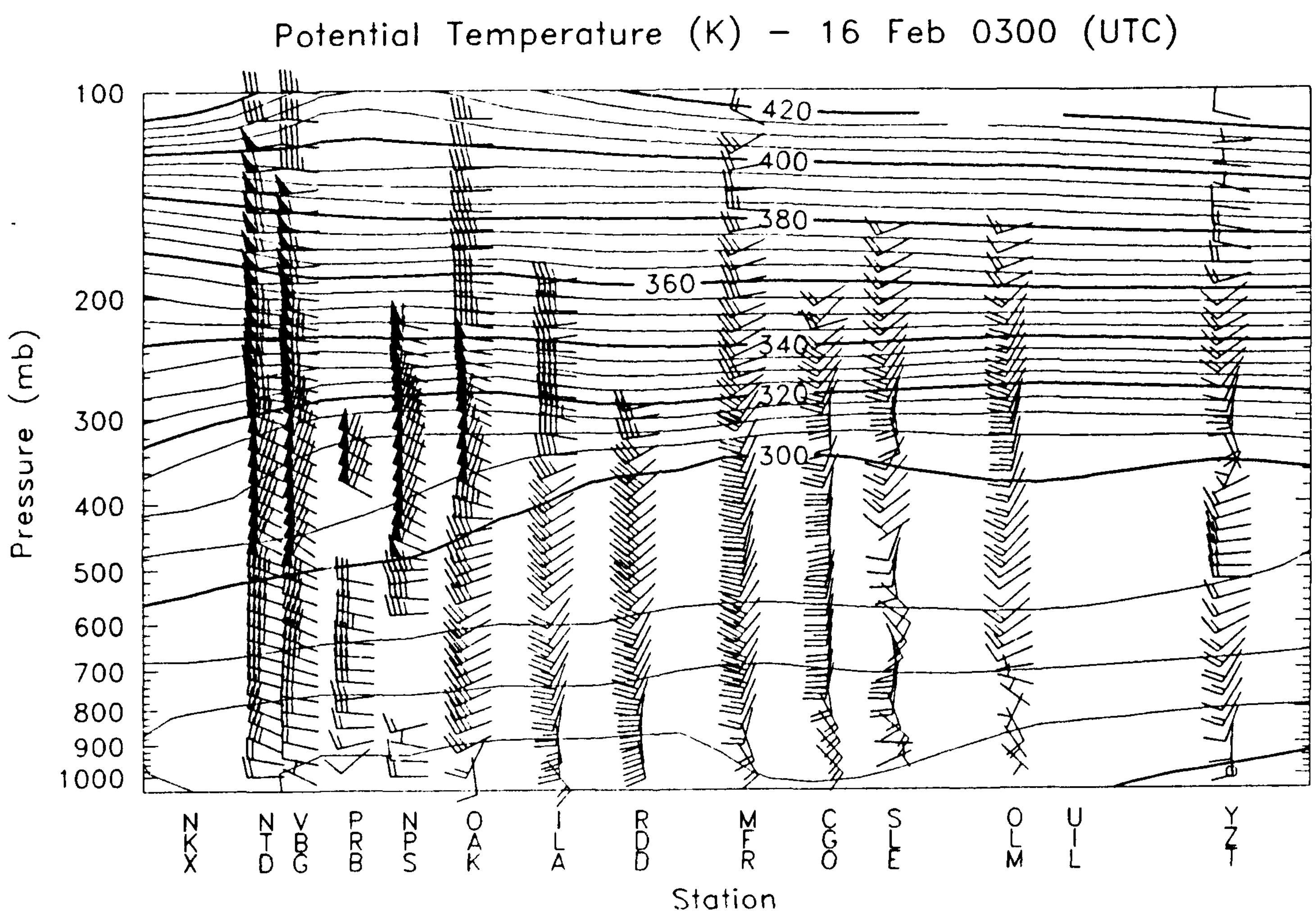

Fig. 22 As in Fig. 18, except for 0300 UTC 16 February 1992.

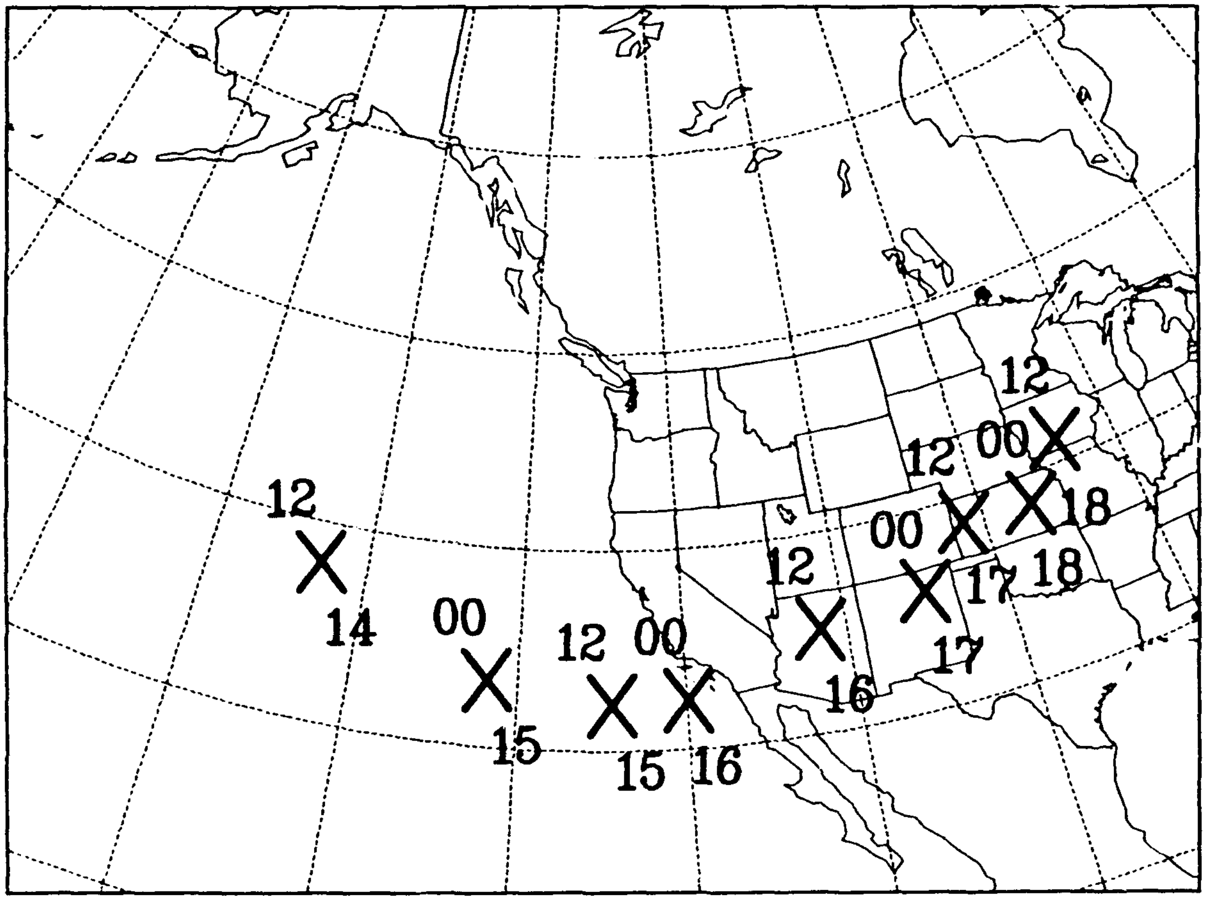

Fig. 23 As in Fig. 19, except during PIOP 2 from 1200 UTC 14 February through 1200 UTC 18 February 1992.

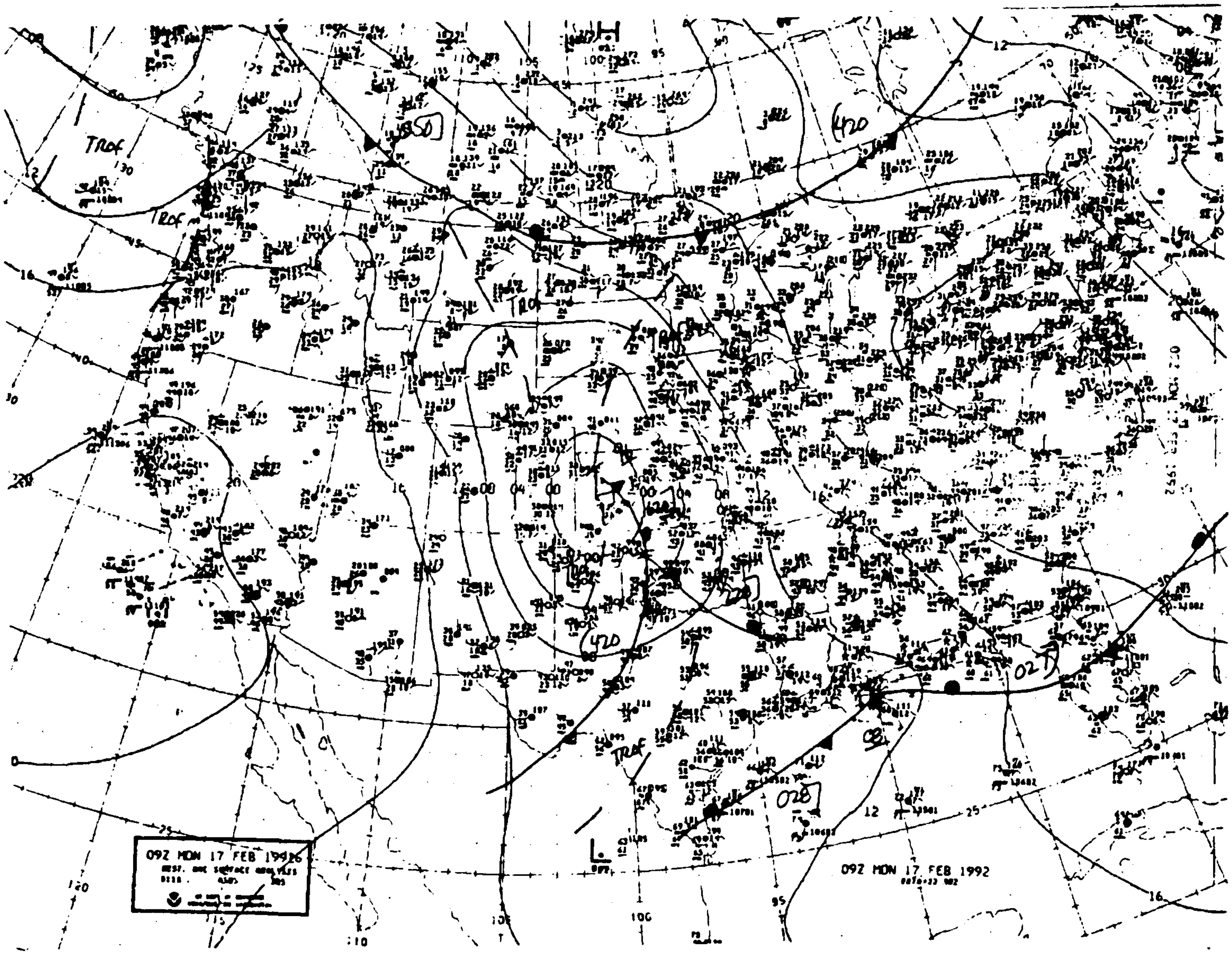

Fig. 24 As in Fig. 20, except for 0900 UTC 17 February 1992.

with PIOP 2 include the various mesoscale phenomena that occurred while the disturbance propagated through the STORM-FEST region as well as the impact of the vorticity center associated with the main upper low, which moved inland from Oregon.

c. PIOP 3

(0000 UTC 20 February - 0000 UTC 21 February)

Summary

The feature of interest during Picket Fence IOP 3 (PIOP 3) was a fast moving subtropical disturbance that crossed the full extent of the Picket Fence observing network. The 500 mb vorticity maximum associated with this short wave crossed the central Oregon coast around 1200 UTC 20 February. Weak lee-side surface troughing and cyclogenesis took place in northwestern Texas around 1200 UTC 21 February. STORM-FEST conducted two limited IOPs (SIOPs 9 and 10) on this system but no special 6-h NWS soundings were taken in the Intermountain Region.

Synoptic Discussion

After the passage of PIOPs 1 and 2, a more zonal flow pattern became established across the eastern Pacific and western U.S. as the southern branch of the jet stream continued to migrate northward. The disturbance associated with PIOP 3 dropped into this zonal southern branch flow north of Hawaii and quickly moved eastward. At the start the PIOP on 0000 UTC 20 February, the 500 mb vorticity center associated with the disturbance was located near 41^{o} N, 131^{o} W (Fig. 25). This vorticity center crossed the Central Oregon coast around 1200 UTC 20 February with an associated 43 m s^{-1} jet streak at 740 mb over Cottage Grove, OR (CGO) (Fig. 26). During the next 24 h, the wave moved inland and weakened over the northern Rockies but redeveloped in the lee of the mountains over southern Utah by 1200 UTC 21 February (Fig. 27). The wave eventually interacted with an approaching polar front from the north but was associated with only weak surface troughing and cyclogenesis over Oklahoma and Texas during the next 36 h (Fig. 28). This complicated system, which eventually became the subject of SIOPs 9 and 10, remained weak and moved slowly across northern Texas, southern Oklahoma and

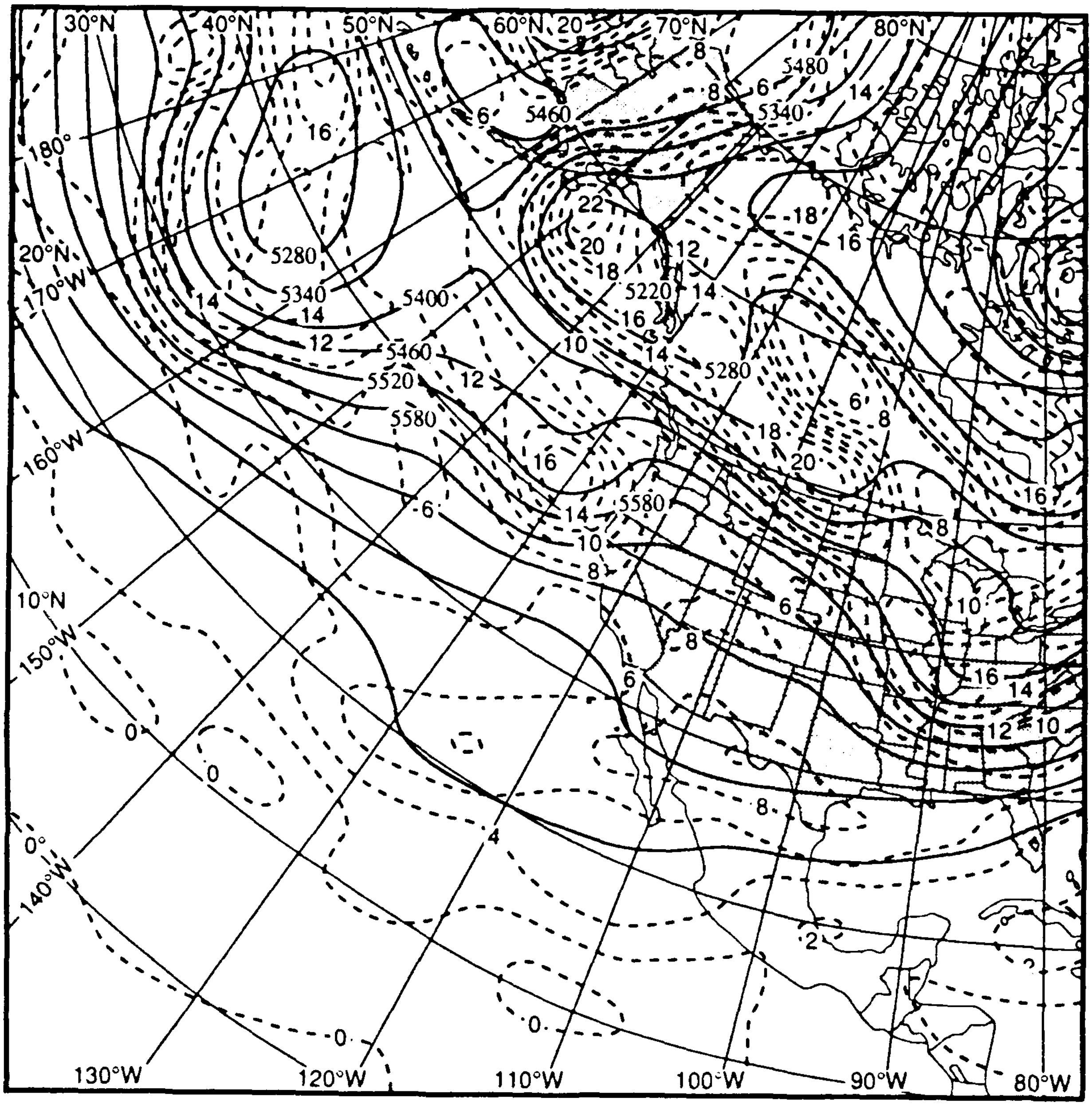

Fig. 25 As in Fig. 17, except for 0000 UTC 20 February 1992.

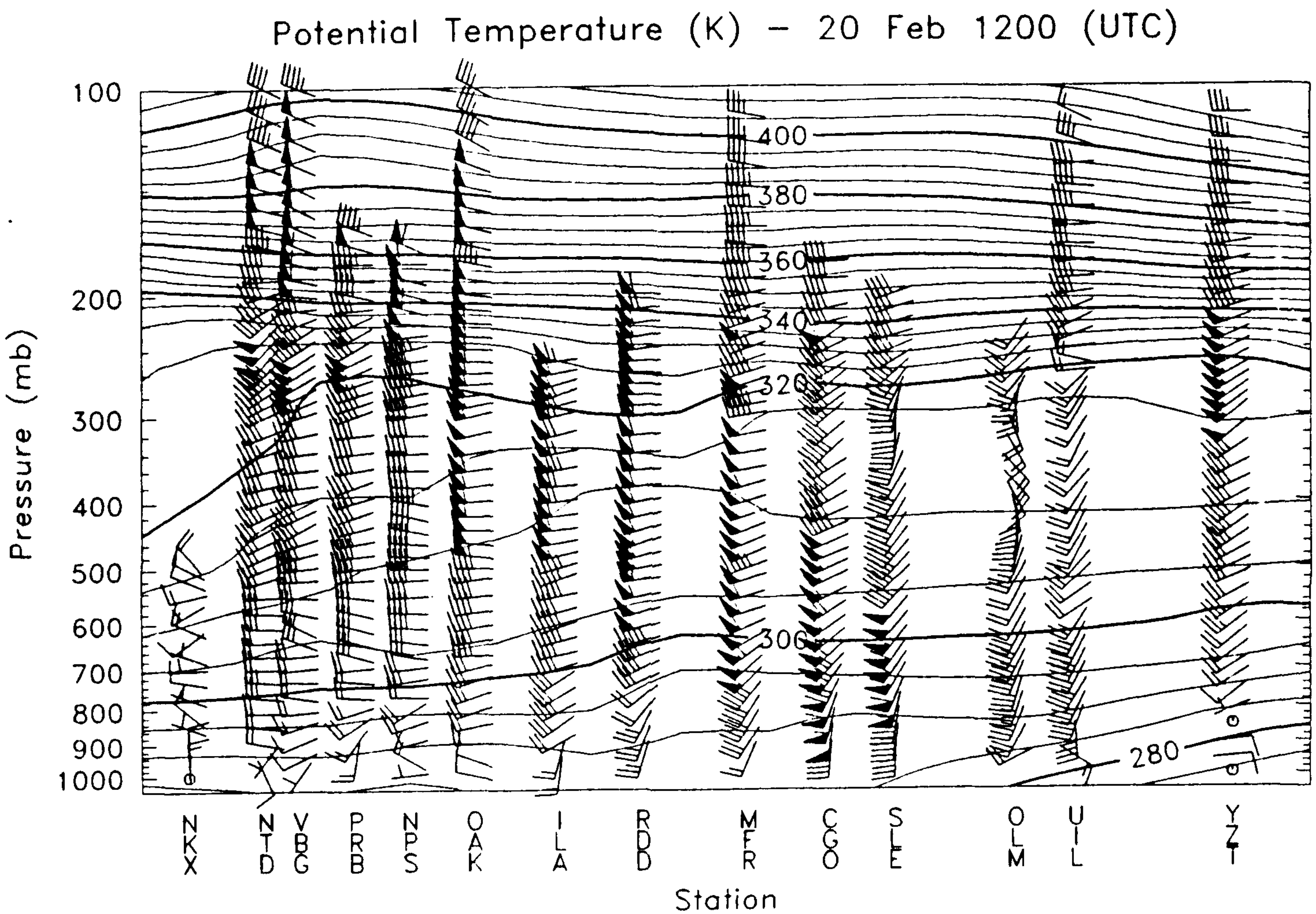

Fig. 26 As in Fig. 18, except for 1200 UTC 20 February 1992.

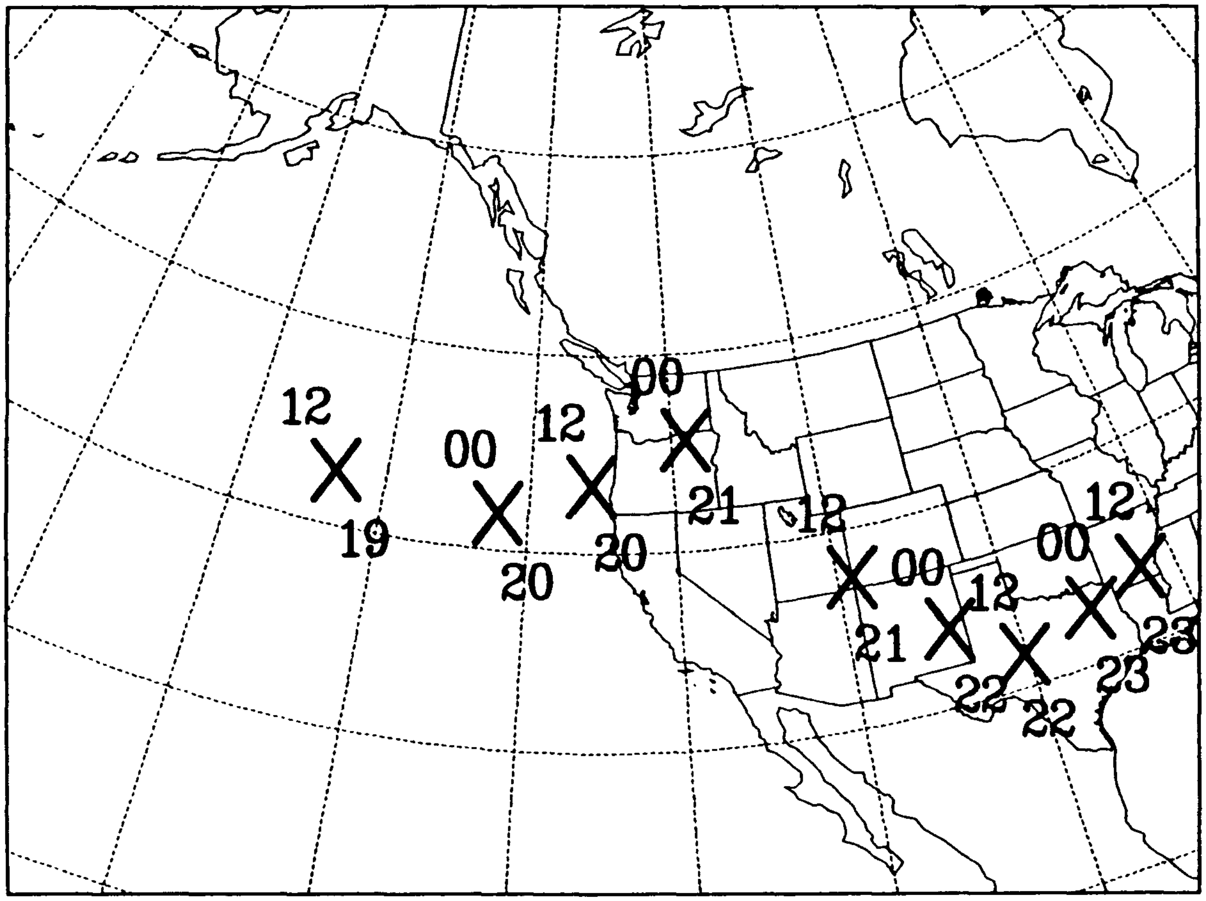

Fig. 27 As in Fig. 19, except during PIOP 3 from 1200 UTC 19 February through 1200 UTC 23 February 1992.

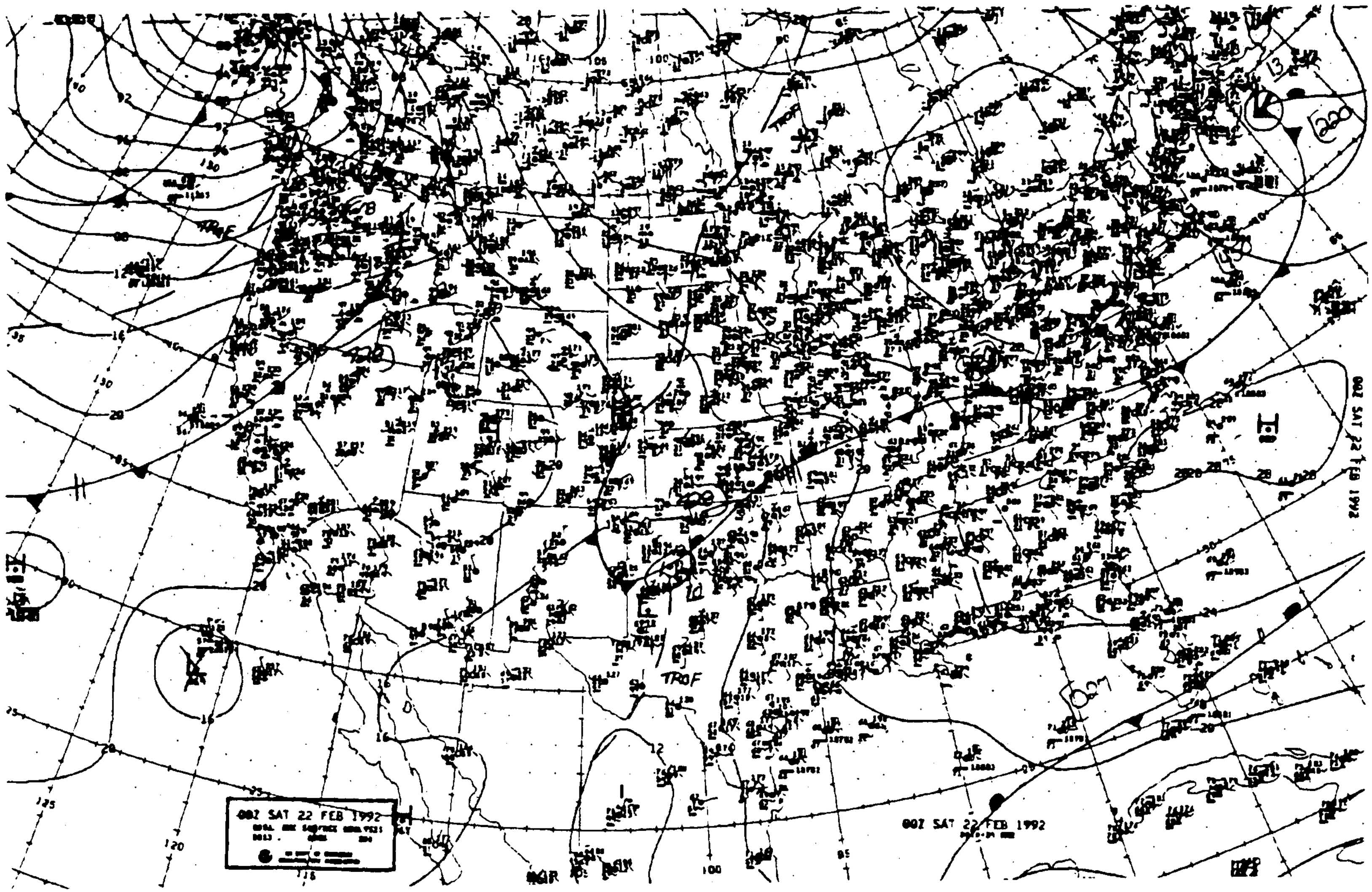

Fig. 28 As in Fig. 20, except for 0000 UTC 20 February 1992.

Arkansas, and out of the STORM-FEST region by 0000 UTC 24 February.

Despite a rather underwhelming surface development, this storm system was interesting for a number of reasons. The NMC analyses of the disturbance over the East Pacific indicated that it was fairly weak with little baroclinic support in the lower troposphere. Additionally, medium-range numerical guidance showed only weak subsequent development over the STORM-FEST region. However, satellite imagery (Fig. 29) indicated a much more robust feature, which prompted the calling of a PIOP. Furthermore, this relatively warm, subtropical disturbance was associated with substantial rainfall over northern California, Oregon and Washington. Unlike typical baroclinic systems, maximum wind speeds were observed between 600 mb and 700 mb as the wave crossed the coast. The shallow nature of the system may explain its dissipation over the Northern Rockies and its subsequent redevelopment to the southeast in the lee of the mountains. It was unfortunate that the Intermountain region sounding network was not activated, since such observations would have been useful in documenting this event. Nevertheless, it will be interesting to define the structure and fluxes of this atypical feature crossing the coast with the extra Picket Fence soundings and to determine whether this system was more intense than numerical guidance suggested.

Although the disturbance was fairly dry by the time it reached the southern plains, some convection did occur in Oklahoma and Texas. A severe thunderstorm watch box was issued at 2135 UTC 21 February for the extreme southern portion of the STORM-FEST. Only weak surface development occurred, presumably because little Gulf of Mexico moisture was available to the circulation as it migrated through the southern STORM-FEST region. An interesting forecast question concerns the contribution of moist inflow ahead of an approaching upper-level system to development at the surface. For example, what are the mechanisms responsible for the inflow, and how does the timing of the inflow and its intensity affect eventual

low-level interaction and coupling with an approaching upper-level disturbance as observed during PIOP 3?

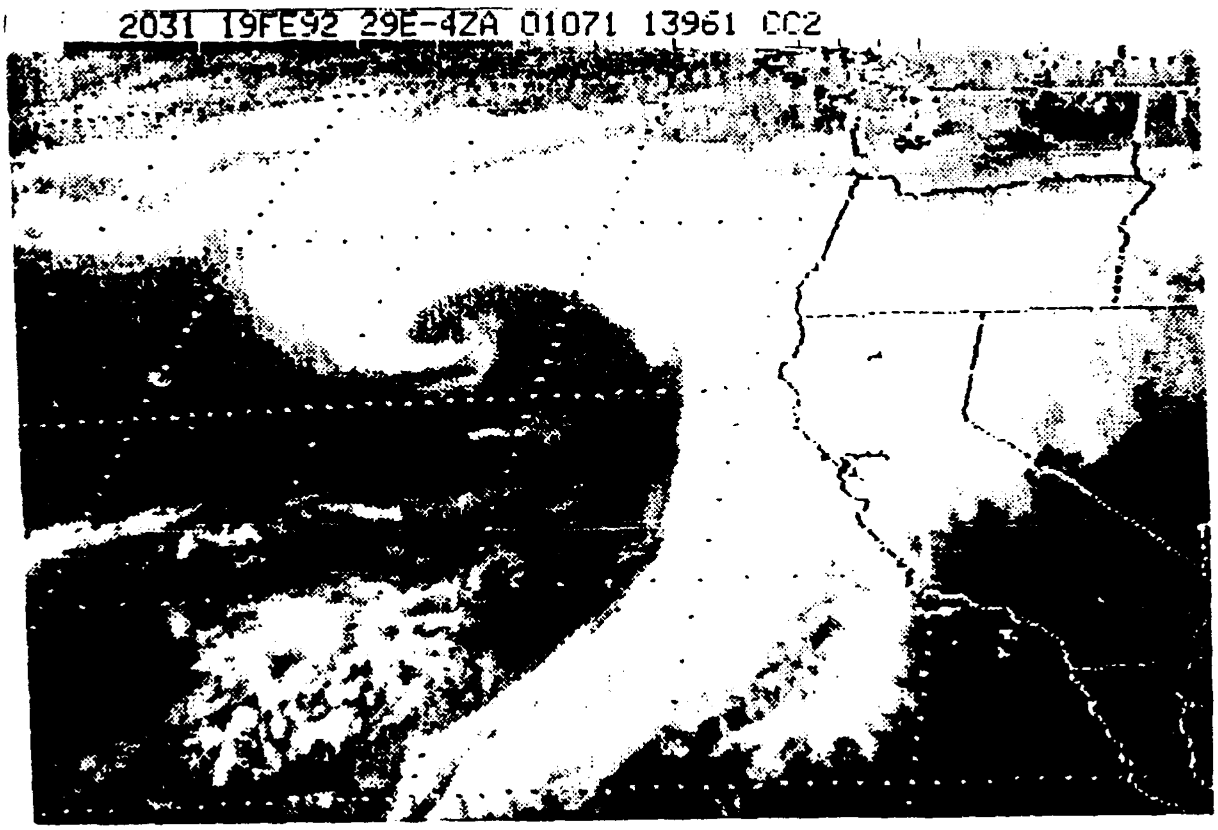

Fig. 29 GOES infrared (11.2 mm) image for 2031 UTC 19 February 1992.

d. PIOP 4

(1200 UTC 05 March - 1200 UTC 07 March)

Summary

The feature of interest during Picket Fence IOP 4 (PIOP 4) was a slow-moving full-latitude trough with embedded short waves rotating through it. Multiple 500 mb vorticity maxima associated with these short waves crossed the West Coast during the PIOP. The most significant of these waves crossed the coast along the California-Mexico border around 1800 UTC 07 March just after the conclusion of the PIOP. Lee-side surface cyclogenesis took place in northeastern New Mexico around 1800 UTC 08 March. This surface low system eventually interacted with a strong arctic front and produced blizzard conditions in northeastern Colorado. STORM-FEST conducted a full-scale IOP (SIOP 17) on this system with special 6-h NWS Intermountain soundings and an aircraft dropsonde flight over the eastern Pacific.

Synoptic Discussion

During the last week of February 1992, a strong ridge again became firmly entrenched along the West Coast, which effectively steered eastern Pacific disturbances north of the Picket Fence into Canada. This ridge began to weaken in early March as a complicated series of wave disturbances approached the West Coast, and created the potential again for Picket Fence and STORM-FEST activity. The first of these disturbances dived south of the Picket Fence as split flow was reestablished off the coast. Eventually, this southern wave closed off over the Southwestern Plains and was associated with cyclogenesis and convective activity in the STORM-FEST region. Shortly thereafter, a second, more northerly wave system approached the coast with more baroclinic support. In addition, a strong arctic front was poised to push southward from Canada and interact with this disturbance as it moved inland.

The 500 mb trough axis was along 130^{0} W at the start of PIOP 4 on 1200 UTC 05 March (Fig. 30). Numerical guidance and satellite 6.7 mm water vapor channel imagery (not shown) suggested that a series of embedded short wave disturbances would rotate around this trough and progress inland as the trough slowly moved eastward and closed off over southern California. The primary short-wave vorticity center crossed the coast near the California-Mexico border around 1800 UTC 07 March. An NWS observation at San Diego, CA (NKX) at 1200 UTC 07 March reported a 34 m s^{-1} wind at 250 mb (Fig. 31), while the 300 mb NMC analysis for 0000 UTC 18 March (not shown) placed a jet streak of over 77 m s^{-1} just off the central Baja, Mexico coast. During the next 24 h, this primary vorticity maxima moved northeastward and was located over southern New Mexico (Fig. 32) at 1200 UTC 08 March as other short wave impulses made landfall behind it. By 1800 UTC 08 March, a 1000 mb lee-side low had developed in northeastern New Mexico along an eastward moving Pacific front (not shown), while a strong arctic air mass and intensifying cold front pushed into the central Plains from the north. The interaction between the Pacific front-cyclone system and the arctic front produced blizzard conditions in northeastern Colorado as the low deepened to 994 mb by 0000 UTC 09 March (Fig. 33) and moved northeastward. Thereafter, the low weakened slightly and migrated along the eastern side of the southward bulging arctic front, and finally moved across southeastern Missouri and exited the STORM-FEST region after 0000 UTC 10 March. After moving through the STORM-FEST domain, the surface system reintensified in the Ohio Valley and eventually caused flooding problems in New England as reinforcing secondary short waves continued to propagate inland around the base of the long wave trough.

This was the first real winter-type event for STORM-FEST and was the highlight event for both the STORM-FEST and Picket Fence experiments. The

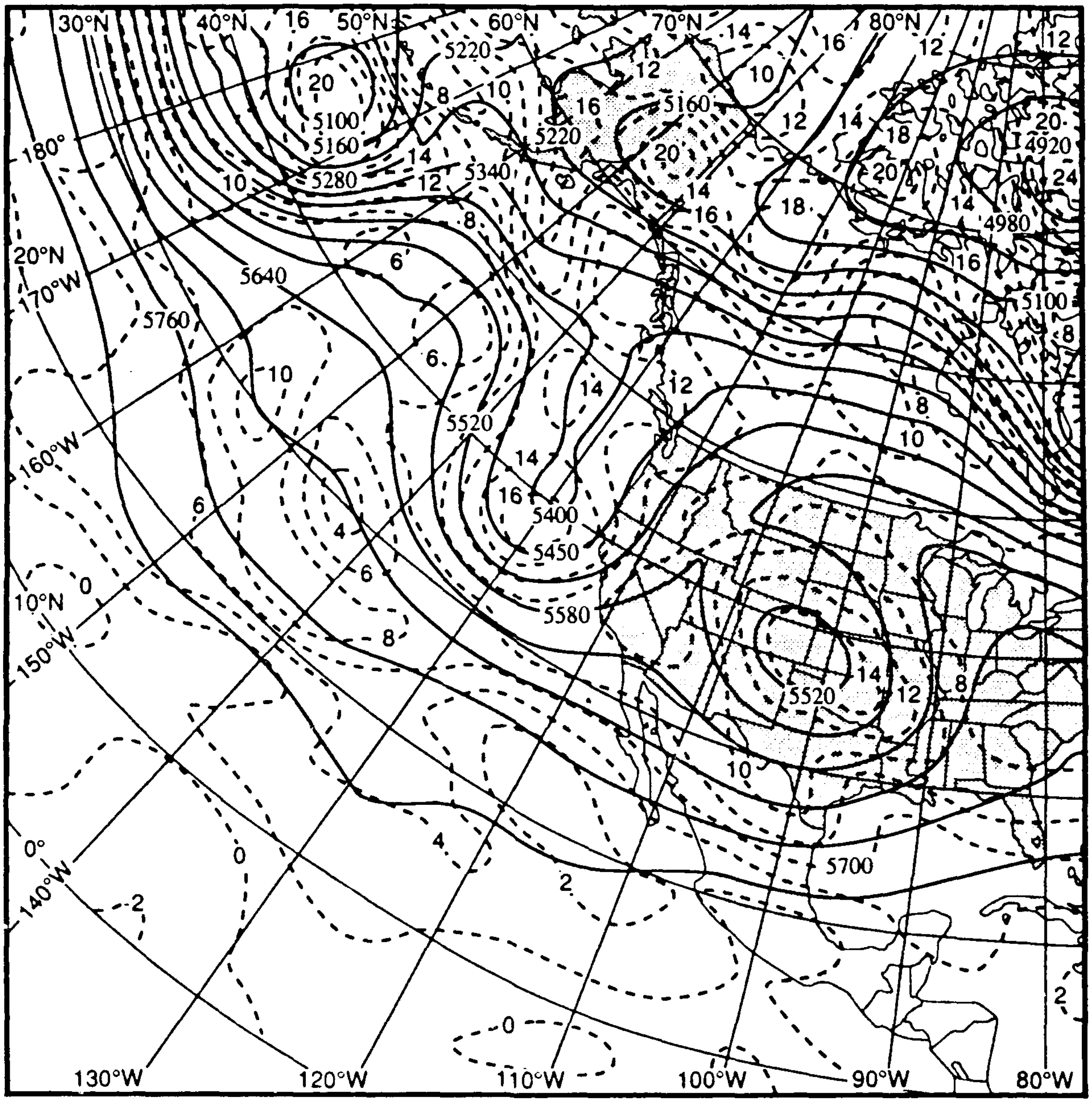

Fig. 30 As in Fig. 17, except for 1200 UTC 05 March 1992.

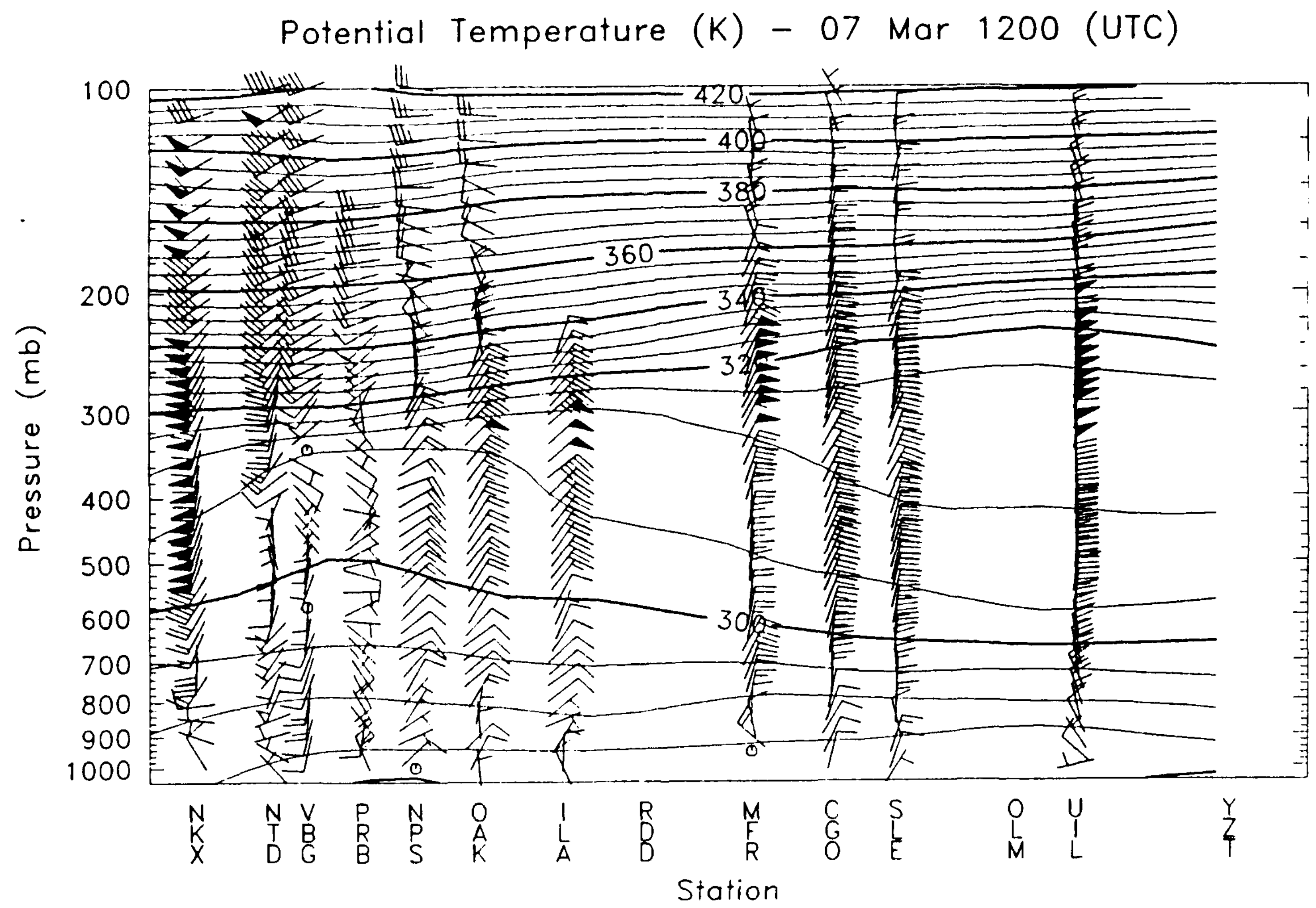

Fig. 31 As in Fig. 18, except for 1200 UTC 07 March 1992.

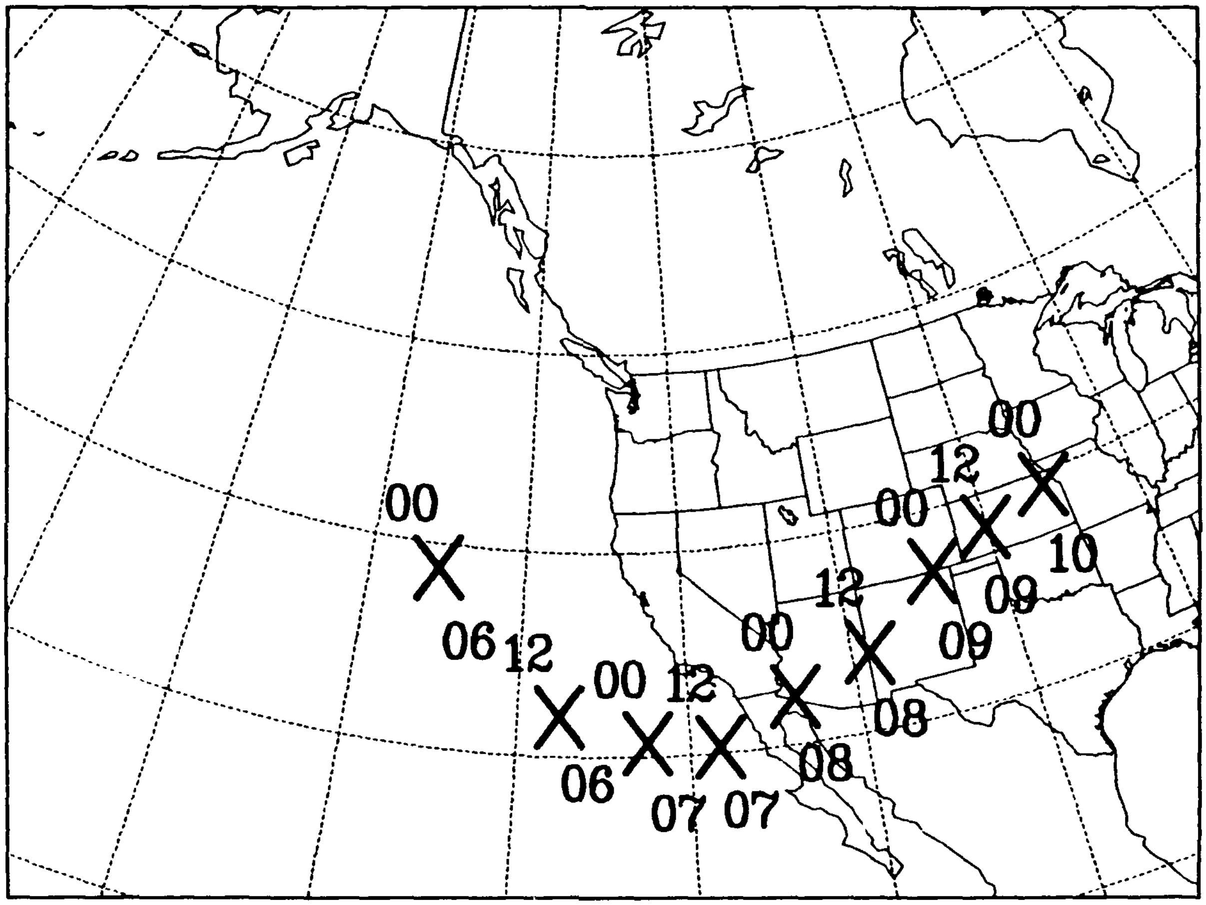

Fig. 32 As in Fig. 19, except during PIOP 4 from 0000 UTC 06 March through 0000 UTC 10 March 1992.

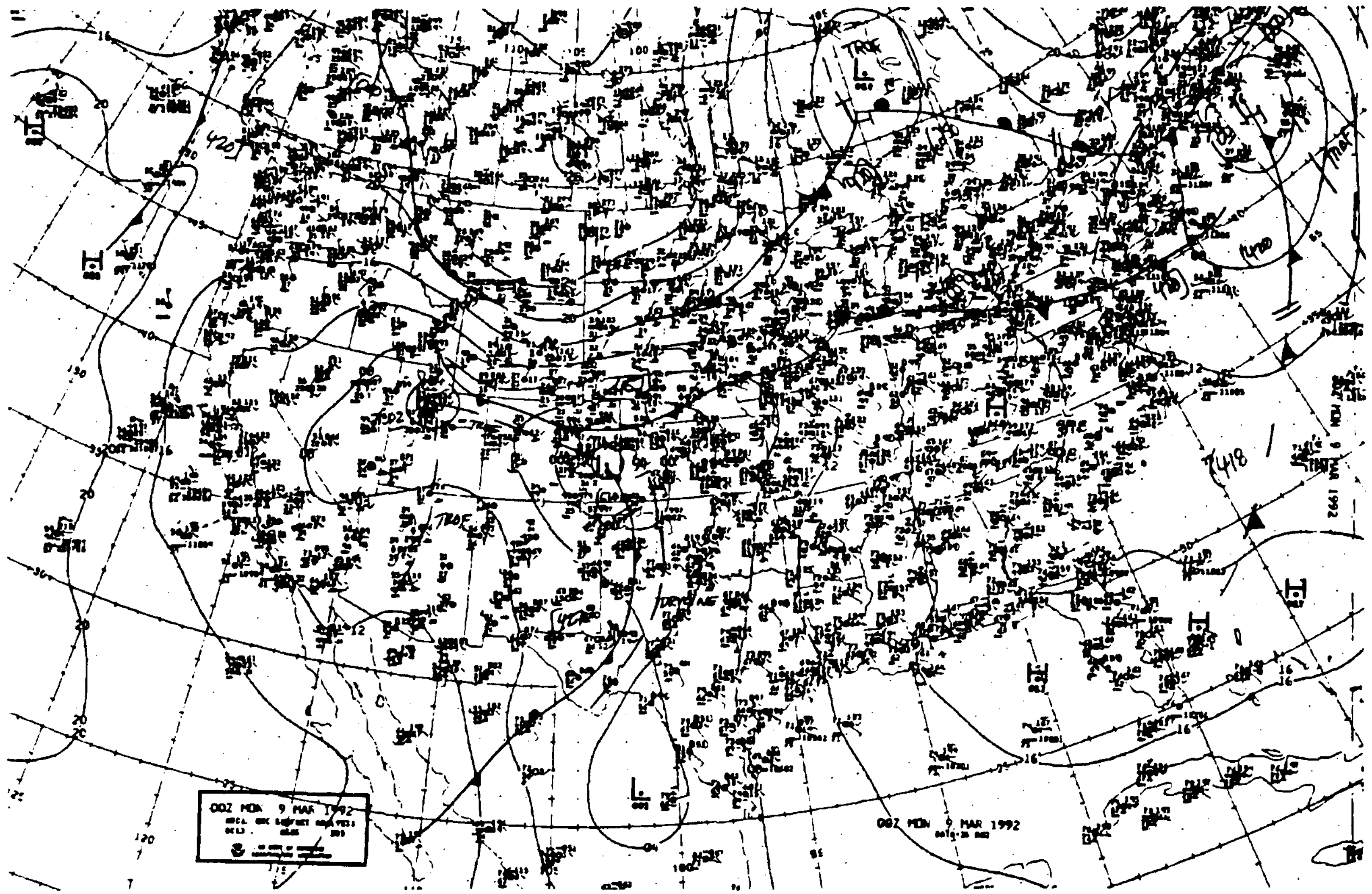

Fig. 33 As in Fig. 20, except for 0000 UTC 09 March 1992.

observations collected during the PIOP and SIOP were highly coordinated and the 0000 UTC 05 March dropsonde data over the eastern Pacific should provide valuable initial and comparison data. The storm brought a wide variety of interesting weather hazards to the Plains, ranging from blizzard conditions in northeastern Colorado to severe convection with hail from western Nebraska to central Texas. Four tornado watch boxes were issued on 0035 UTC 09 March (Fig. 34).

From a forecasting perspective, this disturbance provided another example of the medium-range prediction problem for the central U.S. Divergent numerical model solutions of the event highlighted the difficulty of forecasting the ultimate manifestation of disturbances observed and initialized over the data-sparse Pacific Ocean. Similar to PIOP 2, the event observed during PIOP 4 was characterized by a slowly moving trough with embedded short-wave impulses rotating through it. Accurately locating these impulses over the Pacific and predicting their eventual impact inland, was a challenge that unfortunately prevented optimal timing of the PIOP, which ideally would have extended 12 more hours to 0000 UTC 08 March. Furthermore, a more successful Picket Fence would have included stations in northwestern Mexico to capture the full spatial extent of the main vorticity and jet streak features as they crossed the coast.

As with PIOP 2, the highly coordinated soundings taken over the eastern Pacific and the Picket Fence and Intermountain regions, which began 12 h after the PIOP, should provide reasonably continuous data from which to document the structure and dynamics of this system as it propagated toward the STORM-FEST domain. Central U.S. mesoscale forecasting issues associated with the storm system include: the interaction among the Pacific front, upper-level short wave, and the Arctic front; and the importance of the series of Pacific vorticity impulses to the

mesoscale circulation systems that were associated with the severe weather over the Plains.

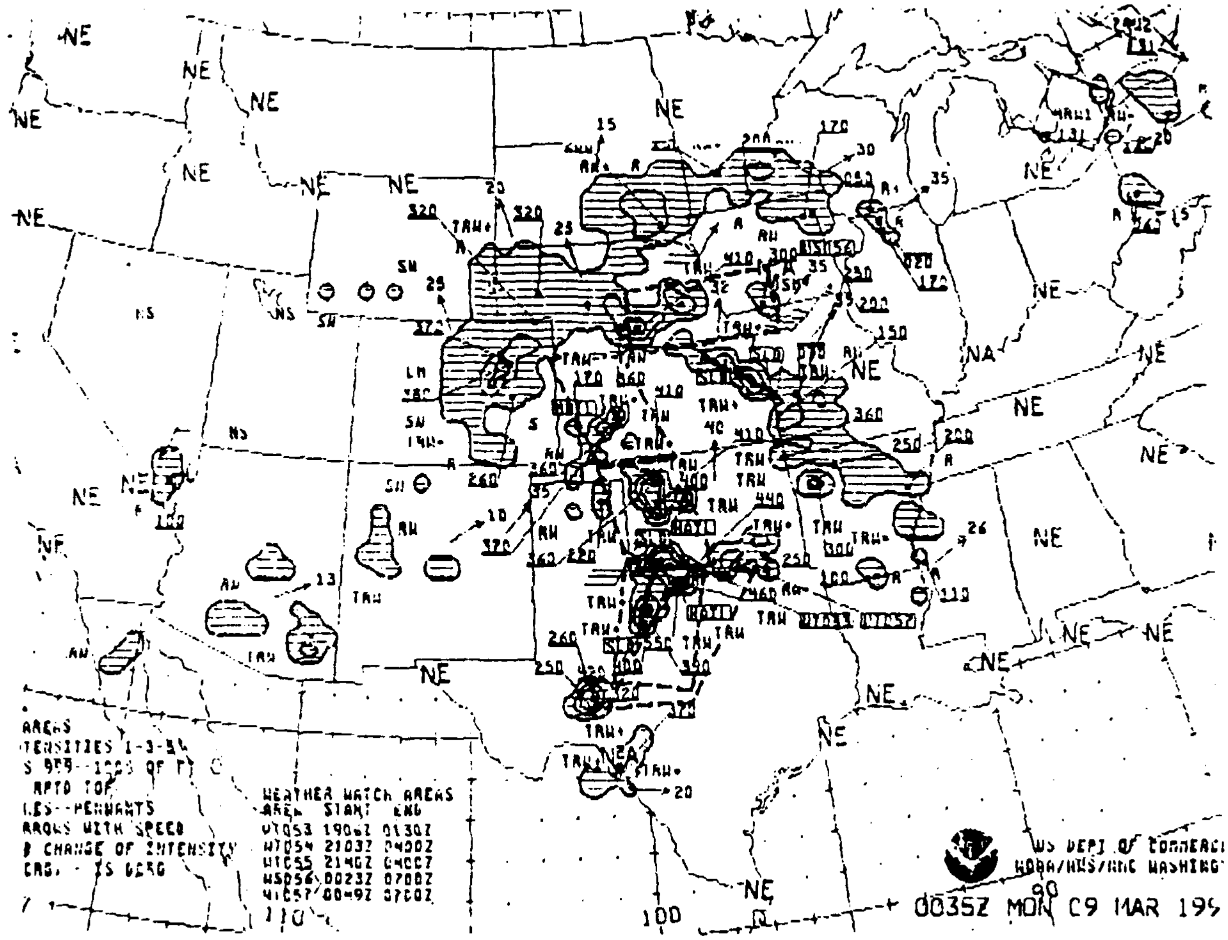

Fig. 34 National Meteorological Center radar summary chart for 0035 UTC 09 March 1992.

5. LESSONS LEARNED

Some lessons learned are recorded in this section for future reference during planning for STORM I or another field experiment similar to the Picket Fence operation. Since this was a feasibility test that was initiated rather late in the planning of STORM-FEST, the most obvious lesson is to begin earlier! This was probably the most important contribution to the logistics and training problems discussed below. Another critical factor was that volunteer observers had to be recruited at the special sites to minimize costs of this feasibility demonstration. We admire (and heartily thank) volunteers who were willing to drive some distance to make 3-h rawinsonde launches at all hours of the day!

a. Training

An ability to consistently achieve 100-150 mb elevations with the rawinsonde launches was demonstrated at the NWS, Air Force and Point Hardy sites that are staffed with professional operators. Another site with professional operators was the Pacific Missile Test Center at Pt. Mugu, which regularly launches rawinsondes as part of their mission. The Mobile Environmental Team (MET) personnel also had been previously trained to use the Mini-Rawinsonde equipment utilized at the Picket Fence special sites. However, they had typically limited their soundings to the lower and middle troposphere, as required for electromagnetic/electro-optical support. Some practice was required to achieve 100-150 mb elevations. As a minimum, the volunteers should have made 3-4 test launches with the same mini-rawinsonde equipment and output devices that would be utilized at the special sites.

Some standard operating procedures were needed to provide guidance about the situations in which it is desirable to initiate another launch. For example, the rule might have been to retry the sounding if the initial sounding did not achieve 400 mb. The standard instructions should include tips from experienced operators, e.g.,

add more helium if it is raining at the time of launch as balloon icing conditions are likely aloft.

b. **Logistics**

The government procurement system requires considerable time to procure sondes, balloons, helium, etc. Consequently, the short timeline of this feasibility test severely taxed the system, and required some extraordinary efforts and arrangements to acquire the necessary expendables.

In retrospect, 200 g balloons should have been the minimum size, and 300 g balloons would have been the preferred choice. The 100 g balloons simply require too much care (and time) to achieve the elevations desired in the Picket Fence. The larger volume balloons would have also reduced the failure rate. Of course, larger balloons require additional helium.

Some additional equipment would have assisted the non-experienced operators to achieve consistently higher elevations. For example, a volume meter should have been available at every special site to ensure proper balloon inflation. A counter weight should also have been available.

c. **Operations**

The most severe operational problem was the coordination of Picket Fence IOPs with the STORM-FEST operations. The conference telephone calls between the forecasters seemed to work well. However, Picket Fence needed to have a representative present when management decisions were made -- both to give input from the Picket Fence perspective, and then to communicate more fully the decision and the reasoning. Of course, the medium-range forecast problems and logistical considerations involved with Picket Fence operations were very different from the short-range focus of many other STORM-FEST components (e.g., the aircraft operations). The timing of the decision for a Picket Fence alert was too early for

the STORM-FEST decision meeting. If this coordination can not be improved, the Picket Fence management would need to have the capability to initiate operations separate from the remainder of operations within the STORM-FEST domain. In the optimum scenario, the Picket Fence would operate continuously using profilers. The next best option would be that sufficient resources would be available to initiate the Picket Fence rawinsonde operations on all potential systems crossing the line, regardless of the likelihood that the system would initiate a mesoscale event downstream.

The planning of the Picket Fence operations needs to anticipate back-to-back cases. That is, periods of benign conditions are frequently followed by a sequence of short wave crossings. Longer periods of operations will tax the NWS site personnel working overtime, as well as requiring more personnel at the special sites.

Arrangements were not made to transmit the soundings from the special sites. Such information may have been useful to the STORM-FEST forecasters. The NWS west coast forecast offices also were quite interested in these soundings. Future cooperation with the NWS may have been facilitated if all soundings had been provided in real-time. The present NOAA communication system is not very flexible for transmitting soundings from special sites. Perhaps a month of advance notice and testing would have been required to use that communication system, and a modem-to-modem arrangement would be needed.

Real-time operations and forecasting at the Naval Postgraduate School are usually limited to weekday classroom instruction. Weekend and 24-h operations require an uninterruptable power supply since power outages have to be expected as the winter weather systems cross the coast. More computer personnel are also desirable to restart the data receipt and other forecast support systems when outages occur.

Another local problem was the need for a dedicated person to perform data archiving functions. Some analyses, forecasts and satellite imagery were discarded that would have been useful during the research phase.

d. **Meteorological aspects**

Perhaps the most significant meteorological effect during the Picket Fence operation was the persistent split flow upstream from the west coast. Evidently due to the El Nino conditions in the eastern Pacific Ocean, the southern branch had stronger flow, was more persistent, and was displaced equatorward. Consequently, the southern jet stream, and its interaction with short waves, was not well sampled by the Picket Fence. At least one station in Mexico would have been useful to extend the Picket Fence southward to better observe the southern branch.

Another consequence of the split-flow regime was that the number of strongly baroclinic cases with a narrow jet crossing the west coast was less than expected. The offshore trough was often broad. This large, slowly moving trough had short waves rotating around the system. Difficulty in forecasting the development of one of these short waves interacting with the southern branch contributed to an inadequate time to get personnel to the special sites at the beginning of IOP1.

As indicated previously, the Picket Fence forecasters were using 96-240 h predictions from the global models. Inconsistency between successive forecasts of the split-flow regime caused considerable difficulty. In some cases, all three model forecasts at a specific time would be compatible. At other times, two model solutions might depart considerably from the third model. It is certainly an indication of the improvement in midlatitude forecast models that useful information was obtained on these medium-range scales. However, the lack of time consistency, or disagreement among the models, are of concern to the forecasters.

This topic will be examined in a future M.S. thesis as a result of the experiences during the Picket Fence operations.

One forecaster rule of thumb that has often been cited during field experiments is that the second (or third) system in a cyclone family will be more intense than the first one. The rationale to "wait for a second system" is that a stronger outbreak of cold air will be involved. This reasoning clearly did not apply over the Pacific during STORM-FEST. Most of the systems crossing were in the southern flow branch. Since these were not the typical fully-baroclinic systems, the second wave was not always the more intense.

The impact of upstream boundary values measured by more frequent soundings at the regular rawinsonde sites often was apparent from increased amplitude of features downstream from the coast. These were not cases in which a synoptic system would have been missed without the Picket Fence observations. Rather, the challenge will be to demonstrate that mesoscale features over the STORM-FEST domain will be better predicted with the improved upstream boundary conditions from the Picket Fence.

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